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THE EFFECTS OF THE ATOMIC BOMB ON HIROSHIMA, JAPAN

Volume I

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Physical Damage Division

May 1947

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THE UNITED STATES
STRATEGIC BOMBING SURVEY

THE EFFECTS OF THE ATOMIC BOMB ON HIROSHIMA, JAPAN

Volume I

Physical Damage Division
Dates of Survey:
14 October–26 November 1945
Date of Publication:
May 1947

~~SECRET~~

This report was written primarily for the use of the U. S. Strategic Bombing Survey in the preparation of further reports of a more comprehensive nature. Any conclusions or opinions expressed in this report must be considered as limited to the specific material covered and as subject to further interpretation in the light of further studies conducted by the Survey.

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FOREWORD

The United States Strategic Bombing Survey was established by the Secretary of War on 3 November 1944, pursuant to a directive from the late President Roosevelt. Its mission was to conduct an impartial and expert study of the effects of our aerial attack on Germany, to be used in connection with air attacks on Japan and to establish a basis for evaluating the importance and potentialities of air power as an instrument of military strategy for planning the future development of the United States armed forces and for determining future economic policies with respect to the national defense. A summary report and some 200 supporting reports containing the findings of the Survey in Germany have been published.

On 15 August 1945, President Truman requested that the Survey conduct a similar study of the effects of all types of air attack in the war against Japan, submitting reports in duplicate to the Secretary of War and to the Secretary of the Navy. The officers of the Survey during its Japanese phase were:

Franklin D'Olier, *Chairman*.
Paul H. Nitze, Henry C. Alexander, *Vice Chairmen*.
Harry L. Bowman,
J. Kenneth Galbraith,
Rensis Likert,
Frank A. McNamee, Jr.,
Fred Searls, Jr.,
Monroe E. Spaght,
Dr. Lewis R. Thompson,
Theodore P. Wright, *Directors*.
Walter Wilds, *Secretary*.

The Survey's complement provided for 300 civilians, 350 officers, and 500 enlisted men. The military segment of the organization was drawn from the Army to the extent of 60 percent, and from the Navy to the extent of 40 percent. Both the Army and the Navy gave the Survey all possible assistance in furnishing men, supplies, transport, and information. The Survey operated from headquarters established in Tokyo early in September 1945, with subheadquarters in Nagoya, Osaka, Hiroshima, and Nagasaki, and with mobile teams operating in other parts of Japan, the islands of the Pacific, and the Asiatic mainland.

It was possible to reconstruct much of wartime Japanese military planning and execution, engagement by engagement, and campaign by campaign, and to secure reasonably accurate statistics on Japan's economy and war production, plant by plant, and industry by industry. In addition, studies were conducted on Japan's over-all strategic plans and the background of her entry into the war, the internal discussions and negotiations leading to her acceptance of unconditional surrender, the course of health and morale among the civilian population, the effectiveness of the Japanese civilian-defense organization, and the effects of the atomic bombs. Separate reports will be issued covering each phase of the study.

The Survey interrogated more than 700 Japanese military, government, and industrial officials. It also recovered and translated many documents which not only have been useful to the Survey, but also will furnish data valuable for other studies. Arrangements have been made to turn over the Survey's files to the Central Intelligence Group, through which they will be available for further examination and distribution.

ACKNOWLEDGMENT

This present report was prepared by the Physical Damage Division of the Survey. The Division officers for the Japanese phase were:

HARRY L. BOWMAN, *Director*.
Lt. Col. CHARLES R. CHAPMAN, *Chief*.
Maj. LELAND N. STEAD, *Executive*.

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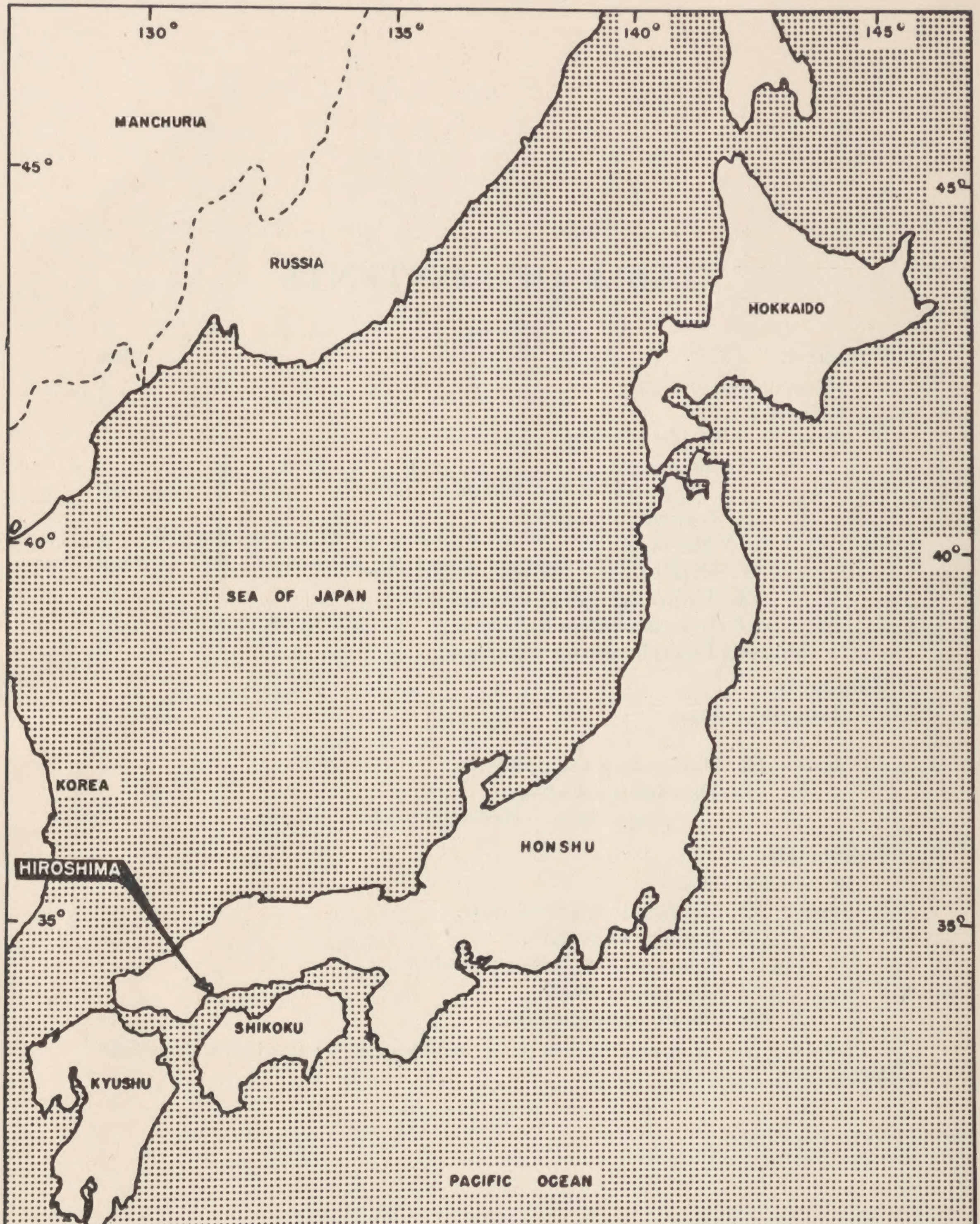
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RUSSIA
HOKKAIDO
40°
SEA OF JAPAN
KOREA
HONSHU
HIROSHIMA
35°
SHIKOKU
KYUSHU
PACIFIC OCEAN
30°

FIGURE 1.

INTRODUCTION

1. The news of the detonation of the atomic bomb over Hiroshima, Japan, shortly after 0800 on the morning of 6 August 1945, was the first intelligence, other than veiled hints, to reach the nations of the world that a nuclear-fission weapon of destruction was in the hands of one of the warring powers. People in general were stunned. Reactions at first were almost hysterical; all sorts of dire prophecies came from the press, the pulpit, and statesmen; modern methods of warfare had become overnight, as it were, totally ineffective and obsolete; no form of protection nor countermeasures against the bomb could ever be devised; in short, the atomic bomb heralded the end of one phase of civilization and initiated a new one, concerning the manifestations of which no one was imaginative or daring enough to hazard a logical guess.

2. As time elapsed and opportunity was had to make dispassionate and scientific appraisals, the picture began to emerge in its true perspective with the result that many of the early and emotional judgments have been modified and even completely changed. Just recently, preliminary reports of the Bikini tests have served to temper even further the first portentous reactions.

3. Study and further experimentation will together point to what is to be done in the future to counteract the effects of the atomic bomb. In the meantime any and all information regarding the bomb's characteristics, behavior, and effects on life, morale, industry, business, utilities, and all aspects of economic endeavor is extremely important to military and civilian planners in their efforts to evaluate the bomb and to provide efficacious countermeasures.

4. As soon as it was considered reasonably safe to enter the city of Hiroshima, numerous investigations, covering all phases of the atomic bomb's destructive forces, were undertaken by different agencies. This report is the result of only one of those investigations. In it no attempt is made to pass judgment on the over-all effectiveness of the atomic bomb, its purpose being only to tell as complete a story as possible of the physical damage suffered by the stricken city as results of both the direct and indirect effects of the bomb's detonation. Reports of damage to buildings of all existing types—industrial, commercial, and residential—are included herein, together with some conclusions concerning the relative degrees of resistance inherent in the several types to the direct and indirect results of the atomic-bomb forces. Likewise, there is considerable discussion regarding building contents' vulnerability and degree of damage in relation to the types of construction. Fire also is reported on at length since it resulted from both direct and indirect causes and was responsible for a large proportion of the physical damage. Other subjects studied and reported on are: damage to machine tools, bridges, stacks, services, and utilities. In each case, when possible, pertinent remarks, conclusions, and recommendations are incorporated in the appropriate sections.

5. A similar complete physical damage report on Nagasaki, the scene of the dropping of the second atomic bomb on 9 August 1945, will be found in Physical Damage Division Report 70.

REFERENCE TABLES

TYPES OF DAMAGE

Damage to Buildings, Industrial and Domestic.

a. Structural: Damage to principal load-carrying members (trusses, beams, columns, load-bearing walls, floor slabs in multistory buildings) requiring replacement or external support during repairs. Light members such as purlins and rafters are not included.

b. Superficial: Damage to purlins and other light members, stripping of roofing and non-load-bearing exterior walls. Damage to glass and interior partitions not included.

Damage to Machinery, Utilities and Equipment.

a. Total: Not worth repair.

b. Heavy: Requiring repair beyond capacity of normal maintenance staff, usually returned to manufacturer.

c. Slight: Requiring repair within capacity of normal maintenance staff.

Damage to Contents Other Than Machinery and Equipment.

a. Total: Not usable.

b. Other: Usable if reprocessed or repaired.

TABLE A.—*Building types or classifications*

[Tables A and B from Joint Target Group]

Group		Type symbol	Description
A. Single-story, no traveling cranes, spans generally less than 75 feet, heights at eaves generally less than 25 feet, area of 10,000 square feet or more.	1. With saw-tooth roofs	A1. 1	All buildings of this group with saw-tooth roofs other than those included in Types A1.2, A1.3, and A1.4.
		A1. 2	Frame and roof slab of monolithic reinforced concrete.
		A1. 3	Exposed top chords of trusses.
		A1. 4	Stressed-skin type of reinforced concrete (e. g. Zeiss Dywidag).
	2. Without saw-tooth roofs	A2. 1	Simple beam and column.
		A2. 2	Arches and rigid frames.
		A2. 3	Truss construction.
		A2. 4	Frame and roof slab of monolithic reinforced concrete.
		A2. 5	Stressed-skin type including concrete shell.
B. Single-story with traveling cranes; any length of span; area of 10,000 square feet or more.	1. Buildings housing heavy cranes.	B1	Buildings containing runways for heavy cranes (capacity 25 tons or more); height at eaves generally more than 30 feet.
	2. Buildings housing light cranes.	B2	All buildings in this group other than those in B1.
C. Single-story; no traveling crane runways; spans greater than 75 feet; height at eaves generally greater than 25 feet; area of 10,000 square feet or more.	1. Main frame members in 2 directions.	C1. 1	Roof trusses supported along one side of building by long span trusses and along other side by columns. Permits large door along one side and at ends.
		C1. 2	Continuous trusses in one or two directions; long span in one direction, supported by columns or exterior walls and by internal columns.
		C1. 3	Exposed chord saw-tooth roof buildings; exposed chord trusses supporting major size trusses at 90°. One or both truss systems may be of long span.
		C1. 4	Diamond mesh arch.
	2. Main frame members in one direction only.	C2. 1	Long-span arches, individually supported along sides of building. May be arranged in multiple spans joined along side.
		C2. 2	Long-span, triangular or bowstring trusses, individually supported by columns at sides of building. May be arranged in multiple spans joined along side, using common columns. Roof pitch exceeds 2 in 10.
		C2. 3	Long-span trusses, top cord of pitch 2 in 10 or less, including exposed cord saw-tooth roofs, individually supported by columns along sides of building. May be arranged in multiple spans using common columns or may be continuous over internal columns.
	3. Shell-type construction	C3	Stressed-skin including concrete shell construction.
D. All single-story buildings of less than 10,000 square feet plan area.		D	This type covers all single-story industrial buildings, regardless of type of construction if under 10,000 square feet in plan area.
E. Multistory, frame buildings.		E1	Earthquake-resistant; extremely heavy steel reinforced-concrete, multistory construction, designed to resist heavy lateral loads.
		E2	Structures in this group other than those in E1.
F. Multistory, wall-bearing buildings. (May have internal columns.)		F1	Earthquake-resistant, wall-bearing construction. (Walls of brick, reinforced concrete, or very massive masonry.)
		F2	Structures in this group other than those in F1.
S. Special Structures		S	Coke ovens, test cells, fuel storage, boilers in power plants, etc.

TABLE B.—*HE vulnerability classes*

HE vulnerability class	Substructural groups (symbols refer to table A)	HE vulnerability class	Substructural groups (symbols refer to table A)
V1	E1.	V4	A1, 1, A1.2, A1.3, A2.1, A2.2, A2.3, A2.4, D.
V2	B1, B2.		
V3	E2, F1.	V4A	C1.2, C1.3, C1.4, C2.3.
V3A	F2.	V5	A1.4, A2.5, C1.1, C2.1, C2.2, C3.

C—*Combustible:* Buildings whose roofs and/or walls are constructed of combustible material. The floors (except the ground floor) are required to be of similar construction. Wood-frame buildings with noncombustible sheeting on roof and/or walls are also included in "combustible" class.

N—*Noncombustible:* Buildings which have no significant amount of combustible material in the structure, but whose structure is susceptible to damage by fire in the contents. An example of this type is a building with exposed steel members which may be warped irreparably by the heat of a fire. Roofs of this type are: corrugated asbestos, corrugated iron, pre-cast or pour-in-place cement or gypsum on exposed steel and reinforced concrete 2½ inches thick or less.

R—*Fire-resistive:* Buildings which have no significant amount of combustible material in the structure and which will withstand all but the most intense fire without structural damage. Roofs and floors (other than ground) should be of concrete more than 2½ inches thick, and the steel frame should be protected and not subject to ordinary fire damage.

C and N, N and R, or C and R used where above types are combined in a single fire division.

SECTION I

OBJECT OF STUDY

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1. General

The over-all objective of Physical Damage Team 1 was the collection, analysis, and evaluation of data pertaining to damage caused by the explosion of the first atomic bomb.

2. Specific

More specifically, matters of primary interest were the causes and extent of damage to structures, equipment and contents of domestic, commercial, industrial, and military installations. Accordingly, the following subject groups for study are established:

a. First Priority.

(1) Damage to Buildings.

(2) Damage to Bridges.

(3) Damage to Services and Utilities.

b. Second Priority.

(1) Damage to Machine Tools.

(2) Damage to Stacks.

3. Other Factors

Precise findings regarding the effects of the atomic-bomb attack on structures and contents were found to be dependent on determinable facts relating to both the target and the attack. It was therefore essential in damage assessment and evaluation to consider such factors as (*a*) the cause and extent of fire; (*b*) history of high-explosive bomb attacks on the city; (*c*) locations of zero points; and (*d*) types of Japanese structures. Of these four items, fire was unquestionably the most important and field investigation thereof yielded interesting and significant data.

4. New Effects

The release of atomic energy in Hiroshima presented a subject of such magnitude that it was impossible for a small group of investigators in a short period of time to develop and assimilate all the evidence available, particularly that which was applicable to new effects and their significance with relation to physical damage. An effort was therefore made to assemble:

a. All available evidence on the phenomena resulting from the almost instantaneous release of an unprecedented amount of energy radiated over wave lengths from those beyond the heat bands of the infrared, through the visible spectrum and into the short wave lengths of the gamma rays. Information on these new effects came from observation of flash burns on materials and persons, from stories of eye witnesses and from official reports.

b. Data on the similarities and differences between the atomic bomb and the conventional high-explosive and incendiary bombs with respect to physical damage.

5. Photographic Intelligence

As a pertinent allied subject, the technique, evaluation, and assessment of damage by means of aerial photos, plus the characteristics of atomic-bomb damage as seen from the air, were considered in relation to the actual facts determined by field study, in order that appropriate changes in interpretation to attain greater accuracy might be effected.

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SUMMARY

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A. FOREWORD

1. General

The survey of Hiroshima was started on 14 October 1945 and completed on 26 November 1945. The over-all objectives were the collection, analysis, and evaluation of (1) data pertaining to physical damage caused by the detonation of the first atomic bomb used as a military weapon, and (2) data on the similarities and differences between the atomic bomb and the conventional high-explosive and incendiary bombs with respect to physical damage. Except where judged pertinent to the report, no study was made of other aspects of the atomic bomb relating to medical measures, morale, and civilian defense.

a. The complement of Physical Damage Division Team 1 comprised 15 officers, 7 enlisted men, and 1 civilian. Attached to the regional headquarters at Hiroshima were 4 officers and 11 enlisted men who had charge of supplies and rations, transportation, photography, and intelligence. Personnel were drawn from the Army and Navy as shown in the following table:

USSBS personnel assigned to Hiroshima

	Physical damage team 1			*Regional headquarters*			
	Army	Navy	Total	Army	Navy	Total	Aggregate
Officers	4	11	15	2	2	4	19
Enlisted Men	1	6	7	8	3	11	18
Civilian	1	----	1	----	----	----	1
	6	17	23	10	5	15	38

b. The team made a field examination and inspection of buildings, machine tools, bridges, utilities, services, and stacks; gathered statistical and documentary material, including Japanese accounts of the atomic-bomb attack and Japanese damage assessments; and conducted hundreds of interrogations and interviews of virtually all the surviving city and prefectural officials. Through eyewitness stories, observations of flash-burns on persons and materials and cooperative work with other teams, considerable information, in addition to the above, was gained in connection with new effects, i. e., the phenomena resulting from the detonation of a nuclear-fission bomb.

c. By the time the team arrived in the field, many people who had fled to the hills immediately after the explosion had returned to the city and were busy erecting flimsy wooden and corrugated-iron shelters on the sites of their former homes. These new structures scattered over the city added somewhat to the difficulties of gathering data, but the returned inhabitants were of some assistance. Since almost all records in the city proper had been burned or otherwise destroyed by the atomic-bomb effects, or lost in the subsequent storms, these people supplied valuable information in tracing specific persons and segregating types of damage.

d. This summary is a presentation of factual material based on a study and analysis of all reliable data gathered in the field and used in the preparation of Physical Damage Division Report 69.

e. Other studies were conducted by the British Mission to Japan and by a team from the Bureau of Yards and Docks, United States Navy, both of which operated under the Physical Damage Division of the United States Strategic Bombing Survey. A separate report is being prepared by each of these investigating agencies.

B. INTRODUCTION

1. Highlights

At 0816 hours 6 August 1945, one of three B-29s over Hiroshima dropped the first atomic bomb ever used for military purposes. An eyewitness who was 2½ miles west of the city stated:

> I saw a single enemy airplane flying over Hiroshima. It dropped or fired a brilliant object. I thought at first that it was an incendiary bomb, but then I saw what looked like a smoke ring from a funnel, gradually falling toward the ground. It grew larger almost immediately and increased in brilliance and soon covered an area almost as big as the city. A flame appeared which was even brighter than the sun. I thought I might get hurt so I fell flat on the ground.

Exploding in the air 2,000 feet above a post office slightly northwest of the heart of the city, the atomic bomb achieved an intensity unparalleled in the history of destruction by a single man-made weapon. As estimated and described by scientists the nuclear-fission bomb had changed into a fireball hotter than the center of the sun (70,000,000° C.) during the detonation that was over in a millionth of a second. It emitted radiations ranging from beyond the heat bands of infrared, down through the visible spectrum and

into the ultraviolet and penetrating gamma rays. The radiations were of an intensity without precedent in human experience. Pressures developed in the bomb were of the order of a thousand billion times atmospheric pressure.

2. Effects

The paralyzing results of the explosion were as unique and spectacular as the bomb itself.

a. Buildings. Approximately 60,000 of 90,000 buildings over an area of 9.5 square miles were totally or severely damaged. Roofs and walls were stripped from other buildings 4 miles from the explosion and glass windows were broken up to 8 miles.

b. Machine Tools. Practically all machine tools were totally or heavily damaged by ensuing fire over an area exceeding 4 square miles; were damaged in varying degrees by fire, debris, and exposure over an irregular 9-square-mile area; and, except where shielded, were subject to exposure damage over a 50-square-mile area of 4-mile radius.

c. Fires. Radiant heat from the bomb and by overturned charcoal stoves, electric short circuits, and other sources of ignition developed a conflagration which consumed all combustible material over an area of 4.4 square miles and overwhelmed what survived of the fire-fighting forces.

d. Public Utilities. All utilities and services were disrupted and damaged, a great many key employees were killed or wounded, and the city was temporarily without transportation, electricity, telephonic communications, gas, water, or sewers.

e. Stacks. Within a radius of 1.6 miles from the point on the ground directly below the point of air-burst (ground zero) 45 percent of all stacks were damaged beyond use.

f. Bridges. Of 81 important bridges scattered over the city's 26.5 square miles, 33 percent of those constructed of wood were totally damaged by blast and fire, but those of concrete and steel construction were not seriously damaged. The entrances and exits of the bridges were clogged with debris from the adjacent collapsed and burning buildings, temporarily trapping the victims on the islands without hope of immediate escape to, or relief from, the outside. Thirty hours elapsed before the first rescue and relief party penetrated the stricken area.

g. Casualties. The dead were estimated at 70,000, with an equal number injured.

C. THE TARGET

1. The City

Beginning as a small fishing village in 1591, Hiroshima (lat. 34°24′ N., long. 132°28′ E.), located in the southwestern area of the principal Japanese Island of Honshu and on the northwestern corner of the important Inland Sea, had developed into an important, modern, administrative, communications, and military center. The seventh largest city in Japan, it had had a wartime peak population of 380,000, but five completed evacuations and a sixth in progress had reduced this figure to an estimated 245,000 by 6 August 1945. The city was built principally upon the fan-shaped alluvial deposits of the Ota River which flowed to the Inland Sea down one of the few valleys running from southwest to northeast across the Chugoku mountain range. The river, crossing the delta by six channels, divided the city into seven fingerlike islands. Except for four small, rocky formations, only one of which was as much as 220 feet high, the delta was uniformly flat and about 10 feet above sea level. By dredging and filling, the natural deltaic islands had been extended to provide land for the growing city. Circled on the west and northeast by a chain of hills 150 to 1,100 feet high, the flat, evenly exposed area stretched 6,500 feet in all directions from the heart of the city over the scattered islands and onto the mainland. Within the city boundaries Hiroshima covered approximately 26.5 square miles.

a. Built-upness. Densely (over 40 percent plan area) or moderately (20 to 40 percent plan area) built-up areas extended for 23,000 feet on the north-south axis and 17,000 feet east-west. Around the heart of the city in a concentric area with a minimum radius of 6,000 feet occurred the greatest density of dwellings and wood-frame buildings. In addition, within this area were located many load-bearing, brick-wall buildings, fewer steel-frame structures, and at least 50 multistory, reinforced-concrete buildings which were representative of the post-1923, earthquake-resistant design. Interspersed among these buildings were the low, flimsily built shops, dwellings and offices of typical Japanese wood design and construction. The street pattern was an irregular block plan with variations imposed by the flow of inter-island traffic and the irregular shapes of the islands.

b. Use. The central area of 6,000-foot radius accommodated, without more than rough functional separation, the principal commercial section of the city and large parts of the residential and military sections, but there were no industries of appreciable size nearer than 8,900 feet to the city center. The industries were located mainly on the eastern perimeter of the city or on the southern ends of the islands. Seventy-five percent of the 245,000 inhabitants at the time of the attack were in the congested 4-square mile city center, giving a density of population in this area of approximately 46,000 persons per square mile. The overcrowding and population density were largely attributable to the geographical limitations imposed by the islands and to the 42 percent of utilizable land area within the city monopolized by the military who, in addition, used 80 percent of the facilities of Ujina Harbor (sec. IV, par. 15).

c. Climate. Having hot, humid summers and mild winters, with a mean annual temperature of 57.9° F. (about the same as that of Baltimore, Md.), the climate was characterized by a rainy season from the latter part of April through June and all of September. Light, warm, southerly winds blew from May through October, and northerlies and westerlies the remainder of the year. The typhoon season lasted from June through October with winds varying up to 75 miles per hour accompanied by torrential rains. Between the dates of the atomic-bomb attack on 6 August 1945 and the arrival of the team on 14 October 1945, two severe storms occurred, of which at least one had an intensity such as would be encountered only once in perhaps 50 or 100 years. These storms, unfortunately, destroyed much evidence of physical damage (especially to bridges) as well as public records and other data which had remained after the attack.

d. High-Explosive Attacks. Prior to the atomic-bomb attack the only aerial actions reported by the Japanese against Hiroshima proper were (1) an attack on 19 March 1945 by 4 or 5 Navy planes and (2) an attack on 30 April 1945 by a lone B–29. The Navy planes dropped two 250-pound bombs and the B–29 dropped ten 500-pound bombs, or a total of 5,500 pounds for both attacks. (A total of seven high-explosive attacks was reported by the Office of Statistical Control, Headquarters, AAF, totaling 58 tons of high explosives and incendiaries.) Since the areas affected by these attacks later suffered severely from the atomic bomb it was impossible to evaluate precisely the effective damage. The following data, therefore, are offered only as a recapitulation of damage figures obtained from interrogation of residents and city officials.

Casualties

Attack of—	Killed	Wounded	Total
19 March 1945	2	None reported	2
30 April 1945	10–15	25–30	35–45

Damage to buildings

Attack of—	Destroyed	Minor damage	Total
19 March 1945	2	None reported	2
30 April 1945	22	2	24

Of the 26 buildings damaged, 22 were typical Japanese domestic structures, 3 were wood-frame, and one was of load-bearing, brick-wall construction. The only fire reported was from a direct hit on a warehouse by a 500-pound bomb. The fire burned for two hours, destroying some electric-wire cable, transformer oil, paint, and a small amount of gasoline.

D. THE ATOMIC-BOMB ATTACK

1. Sources of Information

No details of the attack preparations, approach to the target, release of the bomb, elements of the explosive or method of detonation of the atomic bomb dropped on Hiroshima have been made available for this report. Therefore, the following is an account of the attack as experienced and described by the Japanese themselves. The data were obtained through interrogation and from Japanese reports prepared by the Kure Naval District and the governor of Hiroshima Prefecture.

a. Meteorogical Conditions. The morning of 6 August 1945 was clear, with a few clouds at high altitude. Wind was from the south with a velocity of about 4.5 miles per hour. Visibility was 10 to 15 miles.

b. Conditions in the City. An air-raid "alert" was sounded throughout Hiroshima Prefecture at 0709 hours. Reports of the number of planes sighted were conflicting. The aircraft circled the city and withdrew at 0725 hours. The "all-clear" signal was sounded at 0731 hours.

c. The Attack. The aircraft committed in the

atomic-bomb attack were first sighted at 0806 hours when Matsunaga lookout station reported two enemy aircraft proceeding northwest. This figure was corrected to three aircraft at 0809 hours. The sound of aircraft engines was picked up by the Nakano searchlight battery at 0814 hours. Enemy aircraft were reported heading southwest over Saijo, 15 miles east of Hiroshima at 0815 hours. (No air-raid signal was sounded after the "all-clear" at 0731 hours probably because the authorities and residents were accustomed to formations of enemy planes passing over the city.) Three aircraft arrived over Hiroshima at an altitude of 23,000 feet, with the lead plane 700 to 1,000 feet ahead of two others which were following abreast. The lead plane changed course to the northwest after dropping the bomb. The two following planes released parachutes and changed course to the south. At this moment, within a minute before or after 0817, the atomic bomb detonated.

d. Post-Attack. After the attack, the lead plane headed east or northeast. The other two planes were unreported other than the sighting of one light aircraft proceeding south at low altitude.

E. ZERO POINTS

1. Definition

The zero point may be defined as the point of detonation of a bomb. When a bomb detonates in the air the point has location in both plan and elevation. The atomic bomb at Hiroshima burst in the air. Throughout this report the ground location of the point directly under the point of its air burst is designated as ground zero, abbreviated GZ, and the actual point of detonation in the air is designated air zero, abbreviated AZ. The locations of GZ and AZ were developed from flash-marks found on surfaces readily scorched or spalled by radiant heat from the explosion. Edges of unscorched surfaces, or "shadows" on otherwise burned surfaces, that were shielded by some object in the path of the heat waves afforded directions and elevations for the location of the point of detonation.

a. Location and Elevation. Employing the World Polyconic Grid system of mapping (based on 1,000-yard grids) GZ was located at coordinates 744,200–1,261,850 yards, approximately 700 feet southeast of the east end of Bridge 24, and AZ was found to be slightly above 2,000 feet. The calculations of British and Japanese teams closely approximated the findings of this team.

F. JAPANESE BUILDINGS

1. Masonry and Steel Buildings

From the opening of Japan to trade in 1853, when Commodore Perry sailed his well-armed ships of the United States Navy into Uraga Harbor, until the great Tokyo earthquake of 1923, the design and construction of civic, commercial, and industrial buildings, except those of wood frame, were directed largely by architects and engineers trained in, or imported from, America and Europe. During this period little attention was paid to earthquake-resistant design and the majority of the buildings erected were load-bearing brick-wall or relatively light steel- or concrete-frame construction, generally similar to occidental buildings. The great disaster of 1923, however, caused such severe damage to all types of structures that radical revisions were instituted in construction practices. A national building code based on aseismic design was adopted on 1 July 1924, which required greatly increased strength in all structural framing systems, making them about 50 to 70 percent stronger and 50 percent heavier than usual occidental designs, and, at the same time, through restrictive clauses, discouraged many existing practices in the building industry by making the use of brick, hollow tile, concrete block, and wood economically impracticable except for dwellings and small shops. Because, however, of the economic depression of 1930 and the later need for ferrous metals in the military program, the new code was not enforced. Therefore, except in large cities and industrial centers, the buildings erected in compliance with the code constituted a small fraction of the total number. Some of the important provisions of the new code were:

a. Resistance. All buildings other than domestic structures were designed to resist a lateral force equal to 0.1 the total weight of the completed structure distributed according to the weight of the building.

b. Wood-frame buildings were limited to 30 feet at eaves or 42 feet over-all. Column sizes (areas) were increased about 20 percent over previous requirements and knee braces and other lateral braces were made mandatory.

c. Brick structures were limited to 30 feet at eaves and 42 feet over-all and the maximum length of unsupported wall was set at 30 feet. Walls were required to have a minimum thickness of one-fifteenth the story height or for exterior walls

one-tenth the wall height, whichever was the larger, except that minimum thicknesses of 1 foot for walls less than 18 feet long and 1 foot 4 inches for walls 18 feet to 30 feet long were specified.

d. *Steel-frame buildings* were limited to 100 feet in height. Joints between columns and girders had to be made rigid (capable of resisting moment) and heavy brackets or knee braces had to be used. Diagonal bracing or reinforced-concrete walls rigidly connected to the framing and capable of resisting the lateral aseismic loadings were required. Curtain walls had to be rigidly fixed to the structural frame. Hollow tile could not be used for exterior walls.

e. *Reinforced-concrete-frame buildings* were limited to 100 feet in height and continuity was required in design. Columns were limited to a length to the least dimension ratio of 15 to 1 with 1.25 percent reinforcement, and main beams or girders were required to have double reinforcement and stirrups for their full length. Reinforced-concrete walls and partitions were designed to resist the lateral forces, and curtain walls were subject to the same restrictions as for steel-frame construction.

f. *Combined stresses* for ordinary plus earthquake loadings were required not to exceed ordinary allowable stresses.

2. Wooden Buildings

Despite the encouragement of Western construction practices and the official adoption of aseismic design for large buildings, wood-frame and wood-pole buildings remained of a design and construction indigenous to Japan and unfamiliar to most Occidentals. The great majority of the wood-frame buildings were dwellings, combination shop-dwellings, small commercial and industrial buildings, and military barracks. Together, the dwellings and shop-dwellings comprised the bulk of any Japanese urban target and enhanced to a high degree its vulnerability to fire and blast weapons.

a. *The Traditional City.* Residential areas in Hiroshima, like those in other Japanese cities, were characterized by a high degree of builtupness resulting from a density of population comparable to some of the worst slum districts in large American cities. One- and two-story wood-frame buildings roofed with tile were built almost solidly along the streets, with numerous outhouses, wood garden walls, and fences to their rear, which occupied most of the remaining ground area within the block. Streets were very narrow and laid out in a rectilinear pattern except where topographical features interfered. Sidewalks were seldom found, the street being used for pedestrian as well as vehicular traffic. Open gutters on the sides of the streets carried away drainage and waste water from the houses. In areas where the residential section was not clearly defined, small combination shop-dwellings opened directly onto the street with the owners living to the rear or on the second floor. These buildings, however, did not differ in details of construction from the usual dwellings.

b. *Wood-Frame Construction* was usually the work of local carpenters who, as a rule, were highly skilled in intricate and delicate joinery and finishing but lacked any knowledge of elementary statics. The practices followed made their wooden construction fall far below American standards of strength, rigidity, and weathertightness. Apparently, sizes of the fame members were determined by general practice and the materials available rather than by either calculation or guess of loads and stresses, and members used under the same conditions might vary greatly in size. A minimum of rough hardware or nails was used, the members being joined by wood pegs, mortise and tenon and other joints cut on the job. The weak joints tended to make the members larger than would be used in American construction of a similar type, especially in trusses where the joints failed to develop the strength of the heavy members. In contrast, columns were invariably too slender, their buckling being the most common type of failure in wooden buildings. Other notably poor design details were (1) beams dapped to half their total depth, (2) trusses and beams framed into girders and over wall openings, (3) weak wall plates and lack of column caps or bolsters, (4) lateral knee bracing cut into the slender columns and good only in compression, and (5) heavy burnt-tile roofs set in mud and straw on thin boards. The better wood-frame construction used dimension lumber while the poorer construction, which was more common, utilized wood poles and sometimes half poles. Construction lumber was generally pine or fir.

c. *Wood-Pole Construction,* although employing truss forms, was weak structurally and was not comparable with any type of United States construction. Roofs of tile bedded in mud on wood sheathing and walls of mud plaster (Dozo) over

bamboo lath were common for this type of construction.

3. Blast Vulnerability of Wood Construction

Resistance to blast is roughly inversely proportional to mass and strength. The typical Japanese wood buildings were generally light-frame structures with relatively heavy roofs supported by slender columns. Lateral rigidity was normally provided by moments developed by mortise-and-tenon joints between columns and roof beams. The panel walls of mud plaster on bamboo lath were only lightly fastened to the frame and frequently were stripped without rupturing the frame. The light weight, slender columns and poorly designed joints were points of weakness which rendered the buildings highly vulnerable to damage by blast. Failure commonly resulted either from buckling of external columns by blast or by a mass distortion of the structure away from the direction of blast. Because Japanese residential areas were densely built up with dwellings and shop-dwellings, walls were usually shielded from blast by adjacent buildings. Consequently, failure by mass distortion was probably the most characteristic damage effect since this could readily result from blast impinging on the roofs of buildings.

4. Fire Vulnerability of Japanese Dwellings

General opinion in the United States has been that Japanese dwellings are "tinder boxes." Considering the dwellings collectively in their natural surroundings in a congested city, this opinion is well founded; but considering an individual dwelling set off by itself, the appraisal is inaccurate. Collectively, Japanese dwellings are extremely vulnerable to fire because of the high degree of congestion of residential areas; light, exterior, wood sheathing; broad, open, wood eaves; and air spaces under the first floors. All these features tend to assist fire spread. On the other hand, the heavy tile roofs practically preclude their ignition by flying embers and thatched roofs are usually found only outside city limits.

a. Fire Frequency. Actually, frequency of fires in individual Japanese dwellings is less than one-half that in American houses. This condition can be attributed to the fact that the Japanese dwelling is generally less susceptible to ignition because of the lesser amount of combustible furnishings and the higher moisture content of wood and furnishings. In addition, there are fewer internal sources of ignition and more careful supervision by the occupants. Once a fire progresses beyond the state of incipiency, however, a Japanese dwelling burns rapidly.

G. CAUSE AND EXTENT OF FIRE

1. Conditions Prior to Attack

The city of Hiroshima was an excellent target for the atomic bomb from a fire standpoint: There had been no rain for three weeks; the city was highly combustible, consisting principally of Japanese domestic-type structures; it was constructed over flat terrain; and 13 square miles (including streets) of the 26.5-square-mile city was more than 5 percent built up (i. e., covered by plan areas of buildings). The remainder of the city comprised water areas, parks and areas built up below 5 percent. Sixty-eight percent of the 13-square-mile area was 27 to 42 percent built up and the 4-square-mile city center was particularly dense, 93.6 percent of it being 27 to 42 percent built up.

a. Fire Department. Public fire equipment had been little improved in anticipation of wartime fires. Private fire equipment had been augmented somewhat but instruction to home occupants in its use had been limited to training in combating incendiary bombs.

b. Water Supply. The public water system was fairly adequate for normal fire conditions, although pressure was very low on dead-end mains at the south end of the city. No improvements except the addition of some static tanks had been made for wartime emergencies.

c. Firebreaks. Firebreaks totaling 41,000 feet had been prepared by removing combustible buildings on one or both sides of fairly wide streets. In addition, the Ota River and its branches which divided the city into nine distinct areas were effective natural firebreaks. Complete or part firebreak clearance had been effected around 22 of the buildings studied.

2. Ignition of the City

The temperature resulting from the explosion of the atomic bomb was of great intensity but of extremely short duration. At ground zero, 2,000 feet from the center of heat, the temperature probably exceeded 3,500° C. for a fraction of a second. Only directly exposed surfaces were flash burned. Measured from GZ, flash-burns on wood poles were observed at 13,000 feet, granite was roughened or spalled by heat at 1,300 feet, and vitreous tiles on

roofs were blistered at 4,000 feet.

a. Evidence relative to ignition of combustible structures and materials by heat directly radiated by the atomic bomb and by other ignition sources developed the following: (1) The primary fire hazard was present in combustible materials and in fire-resistive buildings with unshielded wall openings; (2) six persons who had been in reinforced-concrete buildings within 3,200 feet of air zero stated that black cotton black-out curtains were ignited by radiant heat; (3) a few persons stated that thin rice paper, cedarbark roofs, thatched roofs, and tops of wooden poles were afire immediately after the explosion; (4) dark clothing was scorched, and, in some cases, reported to have burst into flame from flash heat; (5) but a large proportion of over 1,000 persons questioned was in agreement that a great majority of the original fires was started by debris falling on kitchen charcoal fires, by industrial process fires, or by electric short circuits.

b. Hundreds of fires were reported to have started in the center of the city within ten minutes after the explosion. Of the total number of buildings investigated 107 caught fire, and, in 69 instances, the probable cause of initial ignition of the buildings or their contents was established as follows: (1) 8 by direct radiated heat from the bomb (primary fire), (2) 8 by secondary sources and (3) 53 by fire spread from exposing buildings.

3. The Conflagration

During the first half-hour after the attack, individual fires spread in all directions; thereafter, spread, at least at the perimeter, was principally toward the city. Although the velocity of the wind on the morning of the atomic-bomb attack was not more than 5 miles per hour, a fire storm, including both wind and rain, began to develop soon after the start of the initial fires. The fire wind, which blew continuously toward the burning area, reached a maximum velocity of 30 to 40 miles per hour 2 to 3 hours after the explosion, and intermittently light and heavy rain fell over the north and west portions of the city. As the fire wind increased in intensity, fires in the city were merging, but practically all fire spread beyond 6,000 feet from GZ had ceased 2 hours after the attack. A large portion of the burned-over area resulted from the spreading and merging of the original fires. Beyond 5,000 feet from GZ built-upness influenced the extent of fire spread.

a. Fire Department. The public fire department sustained an instantaneous, paralyzing blow from which it could not recover. Eighty percent of the firemen on duty were killed or critically injured, 60 percent of the public fire stations were totally damaged and 68 percent of the public fire-pump trucks were destroyed. However, no modern well-equipped public fire department could have prevented the conflagration from developing in the city.

b. Water supply. One major break occurred in a 16-inch water main when Bridge 29 was collapsed by blast. This and a large number of breaks in small pipes above ground in collapsed buildings reduced water pressure in the system; however, the reservoir did not run dry and lack of water was not a factor in the extent of the fire.

c. Fire spread. There were relatively few buildings to which fire definitely failed to spread. The blast of the bomb had rendered practically all wall openings unprotected, or in the case of non-combustible and combustible buildings, had collapsed walls and roofs, or stripped wall and roof sheathing. Thus, conditions were ideal for spread of fire from exposing buildings. The average distance between buildings to which fire may have spread and the nearest burned building was 20 feet, compared with 50 feet to buildings to which fire definitely did not spread. The probability of fire spread increased rapidly but in a decelerating trend as built-upness increased in the lower ranges above 12 percent, and decreased rapidly but in a decelerating trend as exposure distances increased in the lower ranges up to 50 feet. There appeared to be practically a straight line relationship between probability of fire spread and built-upness above 40 percent, and an inverse straight-line relationship between fire spread and exposure distances above 50 feet.

d. Fires within buildings. Once ignited, fires spread inside most of the buildings since practically all had either unprotected interior walls and floor openings or ruptured interior walls and floors after the bomb blast, and most contents were combustible.

4. Extinguishment of Fire

Except in a few reinforced-concrete buildings, almost no effort was made to fight the conflagration except at the outer perimeter which finally encompassed 4.4 square miles. Most of the fire had burned itself out or had been extinguished on the fringe by early evening on the day of the attack. Smoldering persisted in the burned-over

area for three or four days. A combination of the fire wind, fire fighting, streets and low built-upness stopped the fire at the perimeter. The public fire department played a minor role in the extinguishment of the conflagration. Hand fire equipment used in extinguishing incipient fires in a few fire-resistive buildings within the burned-over area and in saving many dwellings on the fire fringe proved to be the most effective fire-fighting equipment. At the fire perimeter, exposure distance had a direct bearing on the extent of fire spread. Fire fighting was a factor in stopping spread of fire in only four of 58 fire-resistive buildings which were fire damaged.

a. Value of firebreaks. Although firebreaks, both natural and man-made, were generally ineffective, their value cannot be discounted entirely. Firebreaks assisted in preventing the burn-out of seven fire-resistive buildings and one noncombustible building. If the bombing had been less accurate at Hiroshima, or if a single bomb had been dropped on a city of greater area, firebreaks might have limited spread of fire.

5. Fire Damage

a. Buildings and Contents. Of the total floor area in the 130 buildings studied, 72 percent of fire-resistive buildings, 59 percent of noncombustible buildings, and 80 percent of combustible buildings were burned subsequent to blast and debris damage; 58 of 64 fire-resistive buildings, 8 of 12 noncombustible buildings, and 41 of 54 combustible buildings within or adjacent to the burned-over area had fire damage. However, fire damage in 4 of the fire-resistive buildings and 1 of the combustible buildings was negligible. Only 3 fire-resistive buildings sustained structural damage by fire. Damage by fire to the interior and contents of fire-resistive buildings greatly exceeded damage by blast and debris. Most of the fire-resistive buildings had combustible interior finish as well as a considerable amount of combustible contents, and combustion in the portion of the buildings which burned was practically complete. Noncombustible and combustible buildings were structurally damaged principally by blast, but fire caused the major part of severe damage to contents. About one-half of the noncombustible buildings and most of the combustible ones had combustible contents.

b. Bridges. Of the 8 bridges damaged by fire all were wood and all were ignited by spread of fire from nearby combustible buildings. The average distance from the ends of the 8 bridges which caught fire to the nearest burned buildings was 35 feet, as compared to 70 feet for the 7 combustible bridges which did not catch fire.

c. Extent of Fire Damage. The blast study determined that the extent of complete structural damage to dwellings in Hiroshima had a mean radius of 7,300 feet measured from GZ, whereas the fire study determined that the extent of complete destruction of combustible buildings by fire had a mean radius of 6,250 feet. Totally damaged buildings within the 7,300-foot radius numbered approximately 59,000 and within the 6,250-foot radius, 50,000. Fewer buildings beyond 5,000 feet collapsed completely, so that secondary fires occurred infrequently except in densely or moderately built-up areas. The extent of fire was influenced principally by the location of the bomb burst, the shape of the densely or moderately built-up central part of the city, and the fire wind.

d. Protective Measures. Precautionary fire measures were ineffective largely because of widespread blast damage, the high casualty rate, innumerable fires started throughout the city on both sides of the natural and man-made firebreaks, and the knock-out blow to the fire department. Standpipes and hose in fire-resistive buildings were not used because of casualties to personnel. There were no automatic sprinkler systems in Hiroshima buildings. (It is believed that they could have been of value in buildings strong enough to resist the blast, provided there was an adequate and continuous water supply.) There were no open sprinkler systems for protection of wall openings. (Externally installed systems on reinforced-concrete buildings generally would have remained intact except where directly exposed to the blast.) Steel-roller shutters at exterior wall openings showed a definite inability to withstand the blast pressures. They were completely blown in at 5,200 feet from air zero, whereas steel-hinged shutters on openings of approximately the same size and shape at the same distance were only slightly bent. The steel-roller shutters, however, showed advantages over sliding fire doors at interior wall openings. Reinforced-concrete fire walls in buildings, even in wood- and steel-frame structures with light sheathing, withstood blast pressures, whereas brick fire walls at the same or greater distances from zero were seriously cracked or partly or completely collapsed.

H. DAMAGE TO BUILDINGS

1. Scope of Investigation

The 173 buildings in this study included virtually every reinforced-concrete, every steel-frame and every load-bearing, brick-wall building from GZ to a distance beyond which there was no further effective damage. Selected among buildings constructed of dimension timbers, sufficient wood-frame structures to give a usable sample of construction details and extent and character of damage at varying distances from GZ were studied in detail. In addition, most of the structures of wood-pole construction were located and the approximate extent of structural damage to each was estimated. The mean line of structural damage to residential-type structures was established by field examination and the limits of roof stripping were established and plotted. A summary for each type of construction follows:

a. Because of aseismic design, multistory construction in Hiroshima generally was 50 percent heavier and 50 to 70 percent stronger than in comparable United States practice. However, a small number of buildings of substandard design or construction was found. Concrete was quite variable in quality, some being very poor and the best being about comparable with good United States quality.

b. Light, steel-frame buildings were of excellent workmanship and materials but were slightly lighter than those in United States used for similar occupancies.

c. Load-bearing, brick-wall construction was excellent and compared favorably with better United States and European construction, being if anything, somewhat heavier and stronger than United States construction for similar occupancies.

d. Wood-frame construction, although employing heavier trusses, was weaker than usually found in the United States for similar occupancies because of poor details. Present in Hiroshima was a large number of buildings of weak, wood-pole construction.

2. Cause and Extent of Damage

The primary cause of damage to buildings in Hiroshima was blast, similar to that caused by heavy charges of high explosive but on a much larger scale. The damage from this unprecedentedly powerful and effective blast weapon was characterized by distortion or crushing of entire buildings rather than collapse or fracture of a single member. In many cases, especially in steel-frame buildings, distortion was increased by the subsequent fires. Structural blast damage to dwellings and other wood-frame buildings extended to 7,300 feet from ground zero, which was 1,050 feet beyond the fringe of fire damage. On all types of buildings, wall and roof stripping extended to 22,000 feet from GZ while glass breakage was reported beyond 37,000 feet. Comparison of the atomic bomb with high-explosive weapons results at best in a very rough approximation because of the necessary assumptions. Based upon damage to load-bearing, brick walls an equivalent bare charge of TNT of approximately 4,400 tons was estimated.

a. Mean Areas of Effectiveness (MAE) are based on unsatisfactorily small samples of each class of building studied, except dwellings. Therefore, they should be considered merely as indicating the order of magnitude of damage. The MAE's, especially those computed by the annular ring method (used for all MAE's except residential construction for which the average circle method was employed), are greatly influenced by the height of AZ, and relate only to one particular bomb detonating at one particular height. The mean areas of effectiveness of the atomic bomb for structural damage about ground zero and the radii of the MAE's for the various classes of buildings present were computed to be as follows:

Building classifications	MAE's in sq. mi.	Radii in ft.
Multistory, earthquake-resistant	0. 03	500
Multistory, steel- and reinforced-concrete-frame (including both earthquake- and non-earthquake-resistant buildings)	. 05	700
One-story, light steel-frame	3. 4	5, 500
Multistory, load-bearing brick-wall	3. 6	5, 700
One-story, load-bearing brick-wall	6. 0	7, 300
Wood-frame, industrial-commercial (dimension-timber construction)	8. 5	8, 700
Wood-frame, domestic buildings (wood-pole construction)	9. 5	9, 200
Residential construction	6. 0	7, 300

Values for wood-frame and residential construction are peculiar to Japan and are not applicable to any other locality.

b. Contents damage resulted principally from fire, and, except for multistory, steel- and concrete-frame buildings, contents and structural damage to buildings was generally of similar extent at corresponding distances from GZ. In multistory,

frame construction, fire caused the major portion of all damage to contents, there being 25 to 40 percent initial damage from blast and debris. Contents in light, steel-frame buildings suffered moderate initial damage from blast, but when located in the 4.4-square-mile, burned-over area were practically consumed by fire. Outside the burned-over area there was some exposure damage. In load-bearing, brick-wall buildings within 2,000 feet of GZ, blast and debris were the major cause of damage to contents, additional damage resulting also from fire and exposure. Beyond 2,000 feet from GZ, fire was the major cause. Within the burned-over area practically all contents of wood-frame buildings were consumed by fire with slight to moderate damage from blast, debris, and exposure beyond the fire fringe or burned-over area of 4.4 square miles.

3. Characteristics of Damage

Blast damage to buildings spread uniformly in all directions, resulting in an approximately circular area of devastation. Limiting distances to which buildings were damaged depended upon their strength and construction. Thus, the heavy, strong, multistory, steel- and concrete-frame structures were damaged only in an area relatively near the point of detonation and their burned-out, but otherwise undamaged, structural frames rose impressively from the ashes of the burned-over section where occasional piles of rubble or twisted steel skeletons marked the location of brick or steel-frame structures. At greater distances steel and brick structures remained undamaged. Blast damage to wood-frame buildings and residential construction beyond the burned-over area gradually became more erratic and spotty as distances were reached at which only the weakest buildings were damaged. In the outer sections of the city there were locations where there was no damage other than breakage of glass or minor disturbances of tile roofs.

a. Effects of Pressures. Experiments with high explosives have shown that face-on peak pressures are approximately two to five times as large as side-on peak pressures and consequently greater damage results to walls and roofs facing the blast than to similar surfaces parallel with the blast. These directional characteristics were very apparent at Hiroshima. Thus, near GZ where the blast was almost vertically downwards, buildings were crushed or roofs were crushed with little or no damage to the walls. At somewhat greater distances both horizontal and vertical components of the blast were appreciable and buildings suffered damage both to roofs and to walls facing the blast. At considerable distances from the bomb the blast was traveling in an almost horizontal direction and damage was predominantly to walls facing the blast. Data were not sufficient to determine whether Mach Reflection of the blast wave occurred.

b. Characteristics of Blast Pressures. Blast pressures of high explosives rise almost instantaneously, decay more slowly, and then fall below atmospheric pressure for a period of time usually about three times as long as the period during which they were above atmospheric pressure. The above atmospheric pressure period is termed the positive phase of the blast and the period below atmospheric pressure, the negative phase. Pressure during the negative phase while much lower than that of the positive phase nevertheless results in charcteristic damage such as glass or window shutters blowing out toward the blast. Damage typical of the negative phase was relatively uncommon. The few failures (such as plaster stripping) which could be attributed to the negative phase were in places where the resistance to the positive phase was much greater than to the negative.

c. Shielding. Shielding, or protection from blast by intervening objects, was observed in a few cases. One load-bearing, brick-wall structure was protected from blast by an adjoining building and suffered less wall damage than the average at its distance from GZ. In the eastern part of the city a number of houses which should have been damaged survived because of protection by an intervening hill. Near GZ there was little or no shielding since the buildings were so low compared with the height of AZ that they could not effectively shield one another.

d. Reflection and Diffraction. Both reflection and diffraction phenomena of the blast wave were observed in Hiroshima. Diffraction was evidenced by damage in locations where shielding should have afforded protection, had the blast wave travelled entirely in straight lines. The most frequent evidence of reflection was the destruction of parapet walls on the side away from the bomb while the parapet wall facing the bomb was undamaged, the most probable explanation being that the blast wave reflected from the roof surface reinforced the blast impinging directly upon the wall and resulted in its destruction.

e. Suppositions. Had the point of detonation been lowered, for example to between 500 and 1,000 feet above the ground, it is believed that damage to multistory, steel- and reinforced-concrete-frame buildings close to GZ would have been markedly increased. The extent of damage which would have resulted had the bomb penetrated into the earth is unknown and cannot be approximated until data are available on earth shock and cratering action of the atomic bomb.

I. DAMAGE TO MACHINE TOOLS

1. General

The major industrial plants of Hiroshima were located about 1½ miles from the heart of the city and no damage was done to machine tools in them. Numerous small engineering shops, principally light ones containing 2 to 40 machine tools, were located within the central area. Machine tools in 19 one-story buildings (11 wood-frame, 5 steel-frame, and 3 load-bearing, brick-wall structures) all of which were combustible except one which was noncombustible, were included in this study. There were no reinforced-concrete machine shops. Four of the 19 buildings were outside the burned-over area but were within 7,600 feet of ground zero. Fifteen of the buildings sustained practically 100 percent structural damage. The vulnerability of all buildings to high explosives was V4 (Reference tables).

a. Extent of Damage. All machine tools within 3,500 of GZ were seriously damaged, principally by fire. Throughout the 4.4-square-mile, burned-over area, except in four unburned shops, all machine tools were seriously damaged by fire after sustaining less than 15 percent serious damage by debris. Serious damage to machine tools in excess of 15 percent was caused by debris in only one shop. Weather was the only cause of damage to machine tools outside the burned-over area. The MAE for serious damage to machine tools by fire in combustible buildings was virtually the 4.4-square-mile, burned-over area of the city, but the number of machine tools in various types of buildings in the blast-affected area was much too small to permit calculation of reliable MAE's for serious damage by blast and debris.

2. Machine Tool vs. Building Damage

a. In Wood-Frame Buildings. Debris caused serious damage (total or heavy) to only 3 percent of the machine tools in wood-frame buildings although 64 percent of the total floor area was structurally damaged by blast. Fire was the principal cause of serious damage to machine tools in this type of building. Seven of the 11 buildings were burned and all their machine tools were seriously damaged. Serious damage by fire resulted because of the combustibility of the buildings and their contents, and the congested area in which they were located. A few machines were slightly damaged when overturned by mass movement of the building frames.

b. In Steel-Frame Buildings. Debris caused no serious damage to machine tools in steel-frame buildings although 42 percent of the total plan area was structurally damaged by blast, because the blast rendered mass distortion of the steel frames without tearing loose heavy structural members and wall- and roof-sheathing debris was light. Fire was the cause of serious damage to machine tools in the steel-frame buildings. About 30 percent of the total floor area of the steel-frame buildings was burned out and the same percentage of machine tools in them was seriously damaged by fire.

c. In Load-bearing, Brick-wall Buildings. Debris caused serious damage to only 5 percent of the machine tools in load-bearing, brick-wall buildings although 30 percent of the total floor area was structurally damaged by blast. Fire caused serious damage to 23 percent of the machine tools in this class of building.

d. Weather Exposure. Exposure to weather caused slight damage to machine tools in buildings which were blast damaged but had no fire, and increased the degree of damage to machines which had already sustained heavy damage by fire. Rusting apparently was more severe on fire-damaged machine tools because all lubricants and paint had been burned off.

J. DAMAGE TO BRIDGES

1. Scope of Damage

The atomic bomb caused relatively little structural damage to Hiroshima's 81 important bridges. Scattered over the entire city, 260 to 15,600 feet from GZ, they formed an adequate and efficient bridge system not only for local transportation needs but also as over-crossings for the city's services and utilities, and as a connecting link on the important inland seacoast highway between Osaka and Shimonoseki. The most distant of the 57 bridges studied was 12,200 feet from GZ, but

no atomic-bomb damage was found beyond 7,600 feet from GZ. Evidence of the ability of bridges to resist the forces of the atomic bomb (AZ at 2,000 feet) was as follows: 10 of 19 timber bridges studied were undamaged; 10 of 15 concrete had no damage; and 14 of 23 steel were undamaged. Although great care was exercised in segregating the damage to bridges attributable to the atomic bomb from the flood and typhoon damage occurring on 17 September and 5 October, respectively, there is a distinct probability that the blast loadings from the bomb weakened some of the bridges and left them in a more vulnerable state. Flood and typhoon were credited with damaging to some degree 9 timber, 7 concrete, and 3 steel bridges.

2. Vulnerability

Of the 3 types (timber, steel, concrete), timber bridges showed the least resistance to the atomic bomb. In terms of deck area, it was found that blast and fire from the atomic bomb destroyed 33 percent of the 19 timber, 0 percent of the 15 concrete, and 4 percent of the 23 steel bridges. These percentages do not include such damage as broken railings, curbs, copings and dislodged members, of which 5 concrete and 5 steel bridges showed a moderate amount.

3. Mean Areas of Effectiveness

There were insufficient data on bridges to compute reliable MAE's for all types. The analysis of data, however, led to these conclusions on MAE's for structural damage by blast:

	Square miles
Timber bridges	2. 4
Steel bridges	0
Concrete bridges	0

4. Damage in Relation to Use

Effects on the city resulting from the atomic-bomb damage to bridges considered by class were as follows:

a. Railroad Bridges. The six railroad bridges (5,580 to 8,480 feet from GZ), scattered around a horseshoe circle at the foot of the hills in the northerly part of the city, were as a class most distant from GZ. Strongly constructed of steel, they completely escaped damage except for radiant heat effects which to a minor degree on five bridges discolored the paint on girders facing AZ. As an indirect effect, however, nearby fires resulting from the bomb, debris, and derailed freight cars on Bridge 9 disrupted railroad traffic for 2 days.

b. Street Railway Bridges. The 9 street railway bridges (1,000 to 7,600 feet from GZ) were located generally in the heart of the city. Comprising 2 timber, 1 reinforced-concrete, and 6 steel bridges, the damage incurred was limited to destruction by blast and fire of 1 timber bridge (4,670 feet from GZ) and blast damage to 2 steel bridges located 1,000 feet and 4,670 feet from GZ, respectively. The 2 steel bridges were closed to traffic, 1 for 3 and the other for 30 days. Although closing the latter isolated the Hiroshima railroad passenger station and northeast part of the city from streetcar service for that period of time, the total of all damage to bridges carrying streetcar tracks was not serious.

c. Highway Bridges. The 39 highway bridges comprising 14 timber, 15 concrete, and 10 steel bridges, were most numerous as a class. Scattered over the city, and varying in distance from the nearest (260 feet from GZ) to the most remote bridge (12,200 feet from GZ) included in this study, the effects of the bomb were varied. One steel bridge (1,190 feet from GZ) was totally collapsed by blast. Five steel bridges (260 to 7,600 feet from GZ) and five concrete bridges (4,270 to 6,450 feet from GZ) were damaged in extent varying from distorted and displaced decks and minor structural members to broken railings, curbs, posts, and copings. Five timber bridges were structurally damaged by fire. Despite the six highway bridges totally damaged by the atomic bomb, the damage did not isolate any part of the city or seriously disrupt traffic except for debris on the approaches.

d. Pedestrian Bridges. All four pedestrian bridges (3,200 to 7,960 feet from GZ) were of timber construction. None was damaged by blast, but one (4,760 feet from GZ) was completely consumed by fire which spread from adjacent areas. The loss of this bridge was no serious inconvenience since traffic was rerouted over a structurally undamaged bridge within a distance of 900 feet.

e. Aqueducts and Overcrossings. Seven bridges (four timber and three steel) which served as aqueducts and overcrossings for utilities were structurally damaged by blast and fire. Of these, the four timber bridges and one steel bridge were totally collapsed. The collapse or failure of the seven bridges damaged 5,000 pairs of telephone wire in cables; one 16-inch and one 14-inch-diameter water main; 840 feet of 12-inch-diameter and 410 feet of 8-inch low-pressure gas mains;

and 270 feet of 6-inch-diameter, high-pressure gas mains. To place these utilities in operation would have required complete rebuilding of five overcrossings and repairs to the other two.

f. Other Factors Impeding Usefulness. When considering the usefulness of the bridge system immediately after the detonation of the bomb, factors which should be considered in addition to actual damage to the system were the innumerable fires in areas adjacent to bridge entrances and exits, the debris from collapsed buildings which cluttered the bridge decks and roadways and the general devastation and destruction, which, depriving the city of the use of its bridges, temporarily trapped inhabitants on the islands without hope of immediate escape to, or relief from, the outside. Thirty hours elapsed before the first relief party penetrated the stricken area. Although the bridges generally resisted effectively the blast and fire from the bomb, lack of protection for the approaches and areas adjacent to the ends of the bridges rendered them almost useless at the time they were most needed.

5. Design, Construction, and Materials

The bridges were designed in general to carry lower loadings than are provided in American practice. The design, details and arrangements also appeared to be below United States standards except for the steel-plate, girder, railroad bridges and steel-truss aqueducts which compared favorably with similar structures in the United States. In size, the steel used in bridges was comparable with United States standards. Insofar as could be determined by inspection, the quality of other materials was not equal to that used in similar structures in America. Samples of 2 cast-iron, railing-post sections were taken from Bridges 23 and 24, and were forwarded to the Bureau of Standards, Washington, D. C., on 17 March 1946 for tests. They were found "to correspond to ASTM Spec A48–41, class 20, the classification of lowest tensile strength for gray iron castings. However, the relationships among the tensile, compressive and shearing strength were about the same as in domestic cast irons of the class, and the carbon contents were perhaps somewhat higher, and the silicon and manganese contents considerably lower, than in most comparable cast irons."

6. Resistance of Bridges to Blast Loadings

Since bridges are designed to resist predominantly vertical loads, the fact that those near GZ received the blast forces largely in the direction of their greatest strength tended to minimize the damage to them. As evidenced by plate-girder Bridge 22, (260 feet from GZ and 2,020 feet from AZ) the orientation of the longitudinal center line toward GZ also tended to decrease damage. The extended center line of Bridge 22 passed within approximately 50 feet of GZ. Consequently, horizontal components of the blast were exerted in the direction in which the bridge was most resistant to such forces, while at the same time the probability of damage from reflected blast waves was minimized. Bridge 24 (1,000 feet from GZ and 2,230 feet from AZ), with its extended center line passing approximately 650 feet from GZ, was similar in strength and construction to Bridge 22. However, it was damaged more spectacularly and in a greater degree due to blast forces reflected from the water, and skewed broadside exposure to horizontal components of the pressure wave. Negative pressures were unimportant in causing structural damage, but posts and railings collapsed toward GZ indicated that, at the bridges within approximately 1,000 feet of GZ, there was an inrushing of air following the initial positive blast.

7. Suppositions

It is probable that a bomb similar to the one used at Hiroshima, if detonated at an altitude lower than 2,000 feet, would cause appreciably more damage to bridges near GZ. But the height of detonation which would produce blast loadings exceeding the strength of the bridges is unknown. As discussed in the preceding paragraph, bridges near GZ have the advantage of receiving blast forces in the direction of their greatest strength, and when oriented toward GZ are most resistant to lateral forces as well as less liable to damage from reflected blast pressures. Therefore, the critical point of detonation for bridges would be one at which the blast loadings would be large enough to collapse the bridges by overloading the structural members. At lower altitudes of detonation it appears likely that the radius of damage at Hiroshima would have been decreased, due principally to the bridges being at ground elevation and therefore shielded to the maximum degree. Also, the damage probably would have been less regular in pattern owing to the irregularlity of natural and man-made topographical features. Whether or not the advantage of shielding would have been offset by the probably larger horizontal components of blast against the vertical exposures of the bridge members is speculative.

K. DAMAGE TO SERVICES AND UTILITIES

1. General

The services and utilities of Hiroshima were the following:

a. City railway and bus system.
b. Government railroad system.
c. Electric generating and distribution system.
d. Telephone communications system.
e. Water supply system.
f. Sanitary and storm sewer system.
g. Domestic gas system.

All services and utilities were damaged to some extent and were disrupted in whole or part for varying lengths of time. Since the atomic bomb practically paralyzed the city, however, the demand for services fell off as sharply as the supply, and where services were needed they were restored to, or continued to operate at, minimum levels. To summarize: the railroads were operating through the city on 8 August, 2 days after the attack; some streetcar lines were open by 9 August; the first telephone service was restored by 15 August; electric power was available to some parts of the city by 7 August; the water and domestic gas systems continued to serve outlying districts; and the sewer system, despite the loss of all pumping stations, functioned until the heavy rains of the middle of September raised the water level above the gravity flow lines of the open ditches, flumes, and underground mains.

2. City Electric Railway and Bus System

Hiroshima depended almost entirely upon streetcars and busses for passenger transportation within the city itself and to the outlying vicinities, including the resort town of Miyajima some 10 miles to the southwest. In Hiroshima there were fewer than 25 private vehicles. The greatest recorded passenger traffic was for July 1945 when 4,200,000 persons within the city and 800,000 persons on the Miyajima branch used the cars and busses. The base of operations was the Sendamachi station consisting of 26 buildings, including the main offices, a converter station, warehouses and repair units. The other station, Yagurashita, was a single-building converter station situated in another part of the city, which divided the power output required to operate the system. Both stations received electrical power from the Chugoku Electric Co., of Hiroshima at 22 kilovolts, alternating current, transforming and converting the alternating current to 600 volts, direct current, which was the operating voltage.

a. Equipment. The transmission system was the overhead type supported by wood, steel, and concrete poles. It used a single copper conductor per pair of rails to supply electrical power to the cars. The entire 15.5 miles of the streetcar system within the city was double track, as was 6 miles of the Miyajima section. The rails were of United States and Japanese manufacture having a gage of 4 feet 8.5 inches set on 8-inch ties, 7 feet long. The company operated 123 cars (the largest weighing 18 tons empty and 26 tons loaded) rated at 37.3 kilowatts, and 85 busses to serve areas not reached by streetcars. Since gasoline was critically scarce, a gaseous fuel, produced by equipment on each bus, was employed to operate the motor busses. Eight timber and steel bridges were required to complete the system.

b. Damage to Buildings. Primary blast damage put the entire system out of service. Buildings and equipment at Sendamachi and Yagurashita, 6,400 and 900 feet distant from GZ, respectively, were structurally damaged by blast. Fires that followed completed the destruction at Yagurashita, but the existence of a firebreak north of Sendamachi prevented the ignition of its buildings. The converting equipment at Sendamachi was repaired by 9 August 1945.

c. Damage to Rolling Stock. Of the 123 trolley cars operated by the company, 20 percent were damaged by fire and 45 percent by blast. Of the 85 motor busses, fire damaged 21 percent and blast 26 percent. Radiant heat from the bomb ignited cars and busses within 1,500 feet of GZ. Total damage to cars extended a maximum of 5,700 feet from GZ, heavy damage to 8,400 feet and slight damage to 12,500 feet. Busses were totally damaged at 4,000 feet and heavily damaged 5,500 feet from GZ.

d. Damage to Overhead System. Blast and fire damaged 11.4 miles of the overhead transmission system including damage to 500 wood and 100 steel poles. No damage occurred to concrete poles, the nearest of which were 6,000 feet from GZ. Wood poles were damaged at a maximum distance of 4,500 feet from GZ, and steel poles at 3,500 feet. Overhead transmission cable was downed by blast at 8,000 feet.

e. Damage to Track. With the exception of the bridge crossings no damage occurred to the track system.

3. The Government Railroad System

The government railroad of Japan was the only

system providing intercity transportation for Hiroshima. It maintained the double-track roadbed called the Sanyo Main Line as well as classifications yards, repair facilities, transit sheds, and complete station facilities at Hiroshima. A single-track roadbed connected with Ujina (the only deep-water harbor in the area) to provide rail-to-ship transportation for military matériel and personnel being shipped to continental Asia and other theaters of operations. Transit sheds and stations were also maintained at Koi and Yokogawa, intermediate points within Hiroshima, Yokogawa being the terminal point of the Kabe line. The average passenger rate per month was 1,824,960 persons, while the average tonnage in freight handled was 9,300 tons, requiring 620 cars. However, 6,000 cars per month were shunted through the yards. The roadbed in the area was a fill section with gravel ballast, using 100-pound rails and having a track gage of 3 feet 4 inches. The Sanyo line crossed the branches of the Ota River to the north of the city, thereby limiting the number of bridges to four major and several minor traffic overcrossings.

a. Building Damage. The majority of buildings within the classification and repair area which were between the radii of 8,000 and 10,000 feet from GZ were superficially damaged by blast, while most of those in the station area between the radii of 5,800 feet and 7,400 feet were structurally damaged by fire and blast.

b. Locomotive Damage. There was no damage to locomotives other than glass breakage.

c. Car Damage. Of the 700 freight cars in the Hiroshima division, 45 were damaged by fire and 46 by blast, amounting to 13 percent of the total. Of the 91 passenger cars, 6 were damaged by fire and 77 by blast, or 93 percent of the total, and of the 16 electric cars, 6 were damaged by fire and 6 by blast, or 75 percent of the total. The maximum limit of probable damage to freight cars was approximately 6,800 feet from GZ, and since 93 percent of the passenger cars were damaged within the 6,800-foot radius and 75 percent of the electric cars were damaged at 6,300 feet, the maximum limit for passenger and electric cars was beyond 6,800 feet from GZ. No passenger cars were found beyond the limits stated.

d. Track Damage. There was no damage to trackage or bridge crossings, but because of adjacent fires and blast debris on the tracks, the railroad between Koi and Hiroshima stations was closed from 6 to 8 August. Communications and signalling facilities were not operative because of damage to the communications office in the station area.

e. Cost. The total cost of damage to the government railroads as estimated on 15 November 1945, was 15,800,000 yen or $3,950,000 at the rate of exchange of 4 yen to a dollar.

f. Casualties. Of the 8,467 persons employed, 198 were killed, 140 were missing, 934 were seriously injured and 1,195 sustained minor injuries.

4. Electric Generating and Distribution System

The Chugoku Electric Company supplied the city of Hiroshima with power and light, purchasing all its electrical energy from the Nippon Electrical Co., and selling it to consumers for lighting, heating and motor energy. The total daily consumption was 80,000 kilowatts for lighting and 170,000 kilowatts for heating and motor energy. By the end of September when all substations were operative, 40,000 kilowatt-hours a day were used for lighting and 10,000 kilowatts for motors and heating. These figures represent an 80 percent over-all reduction in the use of electricity.

a. Sources of Power. Hiroshima was only a part of the area served by the Nippon Electric Co., which maintained and operated six hydroelectric plants having a total capacity of 94,200 kilovolt-amperes and one steam-electric plant of 90,000 kilovolt-amperes. These high tension systems were united at the Hiroshima substation rated at 108,000 kilovolt-amperes. They transmitted power to the Hiroshima harbor substation (rated at 12,000 kilovolt-amperes) on the west side of Hiroshima, which distributed the electrical energy through 7 substations in Hiroshima having a total capacity of 34,800 kilovolt-amperes. The Chugoku Electric Co. operated a steam-electric plant rated at 3,500 kilovolt-amperes to augment the Sendamachi street railway substation. All generating and transforming equipment of both companies was manufactured in Japan but was based on designs originating with the Westinghouse and General Electric companies in the United States.

b. 55- and 110-kilovolt Transmission Systems. The Nippon Electric Co. transmitted all electric power by overhead transmission from the hydroelectric plants to the substations at 110 kilovolts. Overhead power transmission from the Saka steam plant was maintained at 55 kilovolts. This plant was approximately 4.5 miles from the substation.

The 55- and 110-kilovolt transmission systems were undamaged.

c. 3.3- and 22-kilovolt Distribution Systems. The substations of the Chugoku Electric Co. transformed from 22 to 3.3 kilovolts for consumer distribution except for the Toyo Industries, Japan Foundry, Hiroshima Electric Railway Co., and the Mitsubishi Shipyard and heavy industries which, having their own substations, received power at 22 kilovolts and transformed to required voltages. Both overhead and subsurface systems for the 22-kilovolt distribution were employed. The overhead consisted of approximately 95,000 feet of 3-phase system. The subsurface consisted of 95,000 feet of 3-phase system with pole-mounted transformers for feeder distribution.

d. Damage to Distribution Systems. Approximately 70 percent of the 3.3-kilovolt overhead and feeder distribution system was damaged by blast and fire. Of the 7,000 poles in service, 4,000 wood poles and 27 lattice-steel poles were damaged by blast and fire. No concrete poles were damaged. Overhead wires were downed by blast 8,000 feet from GZ. Of the remaining undamaged 30 percent of the distribution system, only 90 percent was usable because some areas beyond the points of damage could not be serviced with electricity because of lack of connections to substations. The damage to the substations of Otemachi and Sendamachi made them inoperative and the areas they serviced were distributed among the other substations. There was no damage to the 22-kilovolt subsurface system.

e. Damage to Equipment and Buildings. The equipment in the substations of the Nippon Electric Co., 15,000 and 14,300 feet from GZ, respectively, was undamaged. Of the seven substations of the Chugoku Electric Co., the Sendamachi substation and the steam-electric plant at 7,700 feet from GZ were heavily damaged by fires which spread to the area. The Otamachi substation, 2,400 feet from GZ, was heavily damaged by blast and fires started by the short-circuited equipment. The Dombara, Misasa, and Elba substations were only slightly damaged at distances of 5,500 feet and beyond from GZ. The damage to the Sendamachi substation would have been greatly reduced by adequate fire protection. The remaining two substations were undamaged. The Nippon Electric Co's. Hiroshima substation (15,000 feet from GZ) received minor blast damage, while the Hiroshima Harbor substation (14,300 feet from GZ) was undamaged. The office building of the Chugoku Electric Co. (2,300 feet from GZ) was structurally damaged by blast.

f. Cost. The estimated cost of damage to the Chugoku Electric Co. was 10,000,000 yen, or $2,500,000 at the rate of exchange of 4 yen to a dollar.

g. Casualties. Of the 600 persons employed by the company, 100 were killed, 100 were injured, and 50 were missing.

5. Telephone Communications System

The Bureau of Telephones of the Governmental Communications Department administered and operated all telephone communications within and through the city of Hiroshima, which was divided into two districts. The central district exchange (2,000 feet from GZ) maintained a manually operated system with 5,500 subscribers, and the western district exchange (3,300 feet from GZ) operated a dial-type system with 3,400 subscribers. The average traffic per month was 3,240,000 local calls and 435,000 long-distance calls. All long-distance calls were routed through the central district. Telephones and equipment were of Western Electric design and Japanese manufacture.

a. Transmission Systems. The transmission system consisted of both overhead and subsurface systems. The central district maintained 104,790 feet of overhead cable carried by 4,958 poles and 30,232 feet of conduit-encased subsurface cable. The western District maintained 53,660 feet of overhead cable carried by 2,493 poles, and 9,770 feet of conduit-encased cable. All subsurface cable was buried 4 feet below ground elevation. Intersections occurred at manholes of which there were 223. Because of the number of branches of the Ota River, 18 bridge cable crossings and 9 subriver crossings were necessary. Subriver cable was buried 4 feet below river bottom.

b. Overhead Transmission Damage. Approximately 80 percent of all the overhead system was damaged by blast and fire: 97,280 feet of cable and 4,551 wood poles were damaged in the central district; and 51,280 feet of cable and 2,293 wood poles in the western district. A 10 percent salvage value was estimated. Wood poles were damaged by blast at 4,500 feet from GZ and burned at 6,500 feet. Cable was stripped from hangers at 8,000 feet.

c. Subsurface Transmission Damage. The subsurface system at 4 feet below ground elevation would have been intact if it had not been exposed

to exterior damage at bridge crossings and exit points to the overhead system. There was no blast damage to the conduits and manholes carrying this system. Damage, however, to Bridges 6, 13A, 21, 24, and 29, as well as damage to cable exit points on conversion to overhead, put approximately 80 percent of the subsurface system out of service but most of the cable was salvageable. By 15 August 1945, 35 pairs of subsurface cable had been repaired and were available for use.

d. Building and Equipment Damage. The central exchange (building 43), 2,000 feet from GZ, suffered complete minor damage from blast and fire; fire from short circuits destroyed 100 percent of the equipment. The western exchange (building 85), 3,300 feet from GZ, received minor damage principally from blast, and 50 percent equipment damage from short-circuit fire. It is believed that the enclosed type of equipment used in this building greatly reduced the short-circuit fire hazard.

e. Cost. The estimated cost of damage to telephone communications by the attack was approximately 10,000,000 yen or $2,500,000 at the rate of 4 yen to a dollar.

f. Casualties. Of the 900 persons employed, 350 were killed, injured, or missing.

6. Water Supply System

The city of Hiroshima maintained a water supply system capable of furnishing 20,000,000 gallons of filtered water a day. All water was pumped from the Ota River 3 miles north of the city center to a reinforced-concrete, earth-covered, camouflaged reservoir of 4,500,000 gallons on a hill elevation of 165 feet, 2 miles north of the city center. From the reservoir there was a gravity flow to the distribution system with two booster pumping stations on main feeder lines, and a third at Koi where a 234,000-gallon, reinforced-concrete water tower was maintained. Each housed a 3,600-gallon-per-minute, electrically driven pump rated at 30 horsepower. Water mains varied in diameter from 4 to 30 inches. The water pressure in the center of the city was 40 pounds per square inch, but at dead-end mains at the south end of the city it was only 5 pounds. The fire department took water from the distribution system through below-ground hydrants by means of special connectors and from regular above-ground two-way hydrants. The water supply and distribution system served approximately 90,000 dwellings and buildings and had always proved adequate for peacetime use; no improvements had been made for wartime emergencies. Supplementary sources of water were numerous, including about 100 static water reservoirs scattered over the city, the Ota River and its six branches and many open surface drains. In addition to the water distribution system, 85 percent of the dwellings had dug or drilled wells, equipped principally with hand pumps.

a. Damage to Equipment and Buildings. Damage to the pumping station at 14,000 feet was slight glass breakage, and to the purification plant at 9,000 feet from GZ was 100-percent superficial blast damage. No fires occurred in these areas. One motor in a pump house was burned out because of falling debris and the metering equipment in a meter station suffered heavy damage. The booster pumping station equipment was damaged only slightly, but the wood-frame buildings of stations 1 and 2, which were 2,900 and 3,600 feet, respectively, from GZ, were structurally damaged by blast.

b. Damage to Piping. Eight leaks in the mains were attributed to the attack by the Hiroshima water department officials. Upon inspection, it was the opinion of the team that one leak was developed by action of Bridge 22 which was directly affected by the blast, and that the remaining leaks resulted from falling debris. The mains, which were designed for pressure of 250 pounds per square inch and were buried four feet below ground, were undamaged. Approximately 70,000 branches, one-half to four inches in diameter, were fractured or dislocated when buildings were damaged by blast and fire. One cast-iron pipe (rated at 250 pounds per square inch) four inches in diameter and a few standard hydrants were damaged by falling debris. No flush-type hydrants were damaged. The hydrants of both types were spaced 600 feet apart. Bridge 29 which carried a 16-inch water main was put out of service, however this damage had no effect since a 16-inch main across bridge 30A served the same district. Bridge 43, carrying a 14-inch main, was also damaged by blast and fire, greatly decreasing the water volume in the area served. Floods of 17 September and 5 October 1945 damaged others of the 17 overcrossings.

c. Cost. The cost of damages as estimated on 15 November 1945 was 3,000,000 yen or $750,000 at the rate of 4 yen to a dollar.

7. Sanitary and Storm Sewer System

Because of the delta formation of Hiroshima,

short laterals to the branches of the Ota River were used to dispose of 80 percent of the residential waste water while the remaining 20 percent was carried through branch pipes to the sewer mains. Excreta were not disposed of by the sanitary sewer but were collected by the city and sold as fertilizer. The mains and open flumes were designed as storm sewers to carry off a rainfall of 2.36 inches per hour. (The recorded maximum was 7.87 inches per hour.)

a. Pumping System. Pump stations were used to pump water from the open ditches to the bay areas when, because of high tides, gates could not be opened to permit gravity flow. Electric motors and manufactured-gas-driven engines were used as power units for the pumps, the manufactured gas being produced at each station. Since the gates which permitted gravity flow of water when open, or pumping operations when closed, were manually operated, a station attendant was required in each case to operate equipment and gates to keep the rising waters under control. The water level in the rivers often reached to within one foot of the tops of the revetments during flood stages.

b. Pipe Lines. Because of the absence of human excreta, concrete pipe and open flumes were used extensively. Standard-type manholes were constructed at important intersections and changes in direction, the flow-line depth being a maximum of 10 feet below ground elevation. The sewer system was composed of 211,230 linear feet of open flumes of various sizes, 3,170 feet of 48-inch-diameter clay pipe, 5,970 feet of 48- and 30-inch-diameter concrete pipe and 74,980 feet of concrete-box pipe of varying sizes.

c. Equipment and Building Damage. Of the 14 pumping stations the equipment in 6 within a 5,200-foot radius from GZ was heavily damaged by blast and subsequent fires. The electric motors in stations 1 and 5 were burned out, however, by debris from blast damage falling into operating motors. The remaining stations received slight or no damage from the attack. The electric substations supplying power to the pumping stations were also damaged and could supply no electricity. Two of the buildings were structurally damaged by blast and five by fire. One building received superficial damage by blast and the remaining buildings were damaged to a minor degree. Although the loss of the system was not too greatly felt at that time because of the fair weather and low water, little or no effort was made to repair the damage to the stations, despite the fact that they were not damaged severely. As a result, the seasonal rains caused floods which inundated the revetted areas of Hiroshima and brought the water table from its usual level to within 3 feet of ground elevation. That condition caused serious delay in repairing other utilities which utilized subsurface systems and manholes. The mains and flumes were not damaged, although the latter were clogged by debris in many places.

d. Cost. The city engineers estimated the cost of damage to the sanitary and storm sewer system as of 15 November 1945 at approximately 3,000,000 yen or $750,000, at the rate of 4 yen to a dollar.

8. Domestic Gas System

Approximately 75 percent of the 90,000 residences and buildings in Hiroshima used 1,125,000 cubic feet of producer gas a day at a heat content of 404 B. t. u. per cubic foot of gas. The producer plant was designed by the Japanese to use equipment of both domestic and foreign manufacture. The storage facilities consisted of 2 gas holders, 6,500 feet from GZ, having capacities of 316,000 cubic feet and 211,000 cubic feet, respectively. All equipment was connected by cast-iron screwed pipe with flange and bolt connections. The high-pressure system was developed by pumping from storage through a station regulator. All gas passing through the mains was metered at the station.

a. Piping and Fittings. High-pressure mains were cast-iron screwed pipe, and low-pressure mains were cast-iron, bell-and-spigot, lead-caulked pipes. Pressures of 6 to 8 pounds per square inch were maintained in the high-pressure mains and were reduced by pressure reducers to 6 to 8 inches of water in the low-pressure mains. All piping was buried at four feet below ground elevation. There were 33,000 feet of high-pressure mains and 228,600 feet of low-pressure mains. Valves were sparsely used throughout the system. Pressure reducers were valved between high- and low-pressure mains and the mains were valved at the producer plants.

b. Damage to Equipment and Buildings. Total equipment damage by blast was slight. The electrical switchboard and recording meters were heavily damaged, but no other equipment was damaged. Gas holders were damaged when the crowns of the tanks were torn by the direct effect of the blast and the released gas ignited. The

fires that followed burned timber structures but no additional equipment damage was sustained. The electrical substation supplying this area was also damaged. The 15 buildings dispersed over 2.7 acres, 6,500 feet from GZ, suffered structural damage from blast and fire, and serious superficial damage from blast. In addition severe minor damage was apparent throughout the otherwise undamaged parts.

c. Damage to Piping and Pressure Regulators. There was no apparent damage to the high- or low-pressure mains except at bridges. Damage occurred to branches leading to buildings or dwellings where the latter were damaged. Of the 27 bridges acting as overcrossings, four were damaged by blast and fire, and eight were damaged by floods. Of the pressure regulators installed in the system, two were heavily damaged by blast and fire, the most distant being 1,700 feet from GZ. This damage does not establish the limit of effectiveness, because the low-pressure mains served by the producers would be affected in a degree proportionate to the damage to the producers.

d. Cost. The estimated cost of repair and replacement was 300,000 yen or $75,000.00 at the rate of 4 yen to a dollar.

L. DAMAGE TO STACKS

Hiroshima contained numerous stacks of reinforced concrete, brick and steel, averaging less than 70 feet in height and designed to serve small industries and public buildings. Very few stacks in excess of 100 feet in height had been built in the city proper. Investigation showed the stacks to be generally well designed, but frequently poorly constructed. Analysis of data based on 66 stacks revealed those of reinforced concrete to be the most effective in withstanding the blast of an atomic bomb. Brick proved highly vulnerable, and steel appeared most subject to damage.

It was estimated that within a concentric area of an 8,700-foot radius from GZ (beyond which no further damage to stacks was encountered) 15 percent of the concrete, 50 percent of the brick, and 70 percent of the steel stacks were damaged sufficiently to render them unusable without almost complete rebuilding. In all cases the cause of damage was believed to be blast. Computations for MAE's, using the average-circle method, gave mean areas of effectiveness of the atomic bomb for structural damage by blast against stacks of reinforced concrete, brick, and steel, less than 70 feet high, as 0.3, 2.7, and 4.1 square miles, respectively. The mean effective radii were 1,625, 4,900, and 6,050 feet.

M. PROBABLE EFFECTS ON OTHER TARGETS

1. Targets

The residential, much of the commercial and business sections, and the older industrial sections comprising the major portions of the cities of the United States and Europe are built up predominantly with load-bearing, masonry-wall and wood-frame buildings. Through many of these areas local transportation is by streetcar and bus, and above-ground systems are used for telephone lines and electric power and lighting. Power plants, domestic gas plants, pumping stations, and railroad classification and repair yards have been overrun by the expanding perimeter of the growing cities and are now scattered throughout the city areas. Because of the construction used and the disposition of critical parts of the urban complex, these cities are extremely vulnerable to air-burst atomic bombs. Studies presented in other parts of this report strongly indicate that an atomic-bomb attack against occidental cities would result in tremendous loss of life, collapse and destruction of most of the wood-frame buildings and load-bearing, brick-wall buildings, and almost complete disruption of exposed and congested transportation, service, and utilities systems. In summarizing some of the findings at Hiroshima, the following general conclusions are pertinent in considering probable effects on targets:

a. Blast was the primary cause of damage to buildings, bridges, services, utilities, stacks, and other man-made structures. Extreme damage, however, resulted from fires which burned out the central part of the city, some of which were primary fires started by radiant heat of the bomb.

b. The bomb was an extremely effective and powerful weapon against buildings, being capable of causing severe blast damage at great distances as compared with conventional high-explosive weapons.

c. It was less effective against steel and concrete bridges but highly effective against wooden bridges. In addition, it clogged the approaches of bridges with blast debris from collapsed and burning buildings.

d. It was ineffective against underground installations but was highly effective against over-

head utility transmission lines and at conversion points from underground to overhead, and at utility bridge overcrossings. Utilities, pumping stations, pressure regulators, and meter equipment were damaged in manner and degree commensurate with damage to buildings housing them.

e. It was capable of starting primary fires in exposed, easily combustible materials such as dark cloth, thin paper, or dry-rotted wood exposed to direct radiation at distances usually within 4,000 feet of the point of detonation (AZ).

f. It killed and injured persons in numbers beyond precedent in the history of destruction by a single man-made weapon.

2. Atomic-Bomb Defense

Construction may be designed to make cities less liable to damage from atomic bombs similar to that used at Hiroshima, although future bombs will probably be more powerful and will increase the area of destruction. It is believed, however, that adherence to certain principles established by this investigation would tend to reduce damage substantially below that which would otherwise result, especially in connection with new industrial construction although the principles should hold in general for commercial and residential construction. In the sections of cities which are densely built up with load-bearing, brick-wall buildings little or nothing can be done through passive defense to protect them from almost complete devastation by an atomic-bomb attack. Conclusions in this summary relating to passive defense are concerned principally with reducing damage to future structures and their contents. The two principles of passive defense of great importance in planning, designing, or constructing buildings or cities to resist atomic bombs are:

a. Dispersal.

b. Bomb-resistant construction.

(1) *Dispersal* is most applicable to new construction. It reduces the damage from a single weapon by increasing the distance between targets to a point where the dividends returned in effective damage are not commensurate with the total effort expended in producing and delivering the weapon employed. In consideration of the power of atomic weapons, dispersal implies less the distance between buildings and more the relocation of critical industries in small communities which by their size and number would greatly increase the effort required to destroy or impair the productive capacity of a nation.

(2) *Bomb-resistant construction* may be of several types:

(*a*) Underground construction.

(*b*) Heavy steel and reinforced-concrete, earthquake resistant construction modified to resist large blast forces.

(3) *Effective passive resistance* against physical damage from an atomic bomb would be successful in proportion to the employment of both principles outlined above. Specific considerations would be:

(*a*) Since there was a comparatively small return in immunity at Hiroshima from fire spread among combustible buildings averaging one and one-half stories with an increase in exposure distance above 50 feet and, likewise, by a decrease in built-upness below 12 percent, residential areas of combustible construction should not exceed a density (built-upness) of 12 percent or have exposure distances of less than 50 feet. Bridges of wood construction should have about a 75-foot clearance from combustible areas to prevent fire spread.

(*b*) Natural and man-made firebreaks through urban areas and around buildings are effective in preventing fire spread and conflagrations.

(*c*) Fire departments, pumping stations, electric generating plants and substations, and telephone exchanges should be housed in heavy bomb-resistant structures with separate auxiliary power units for critical equipment. Utilities should be underground loop systems with strongly constructed manholes or housings for pressure regulators, meters, and control valves. To prevent short-circuit fires, electric motors, generators, and telephone exchange equipment should be dustproof.

(*d*) If bomb-resistant shelter is provided for operating personnel, standpipe and hose systems would be effective in combatting internal fires in buildings. Automatic sprinkler systems inside buildings would reduce contents' damage and open sprinkler systems at wall openings would reduce fire spread between buildings. The value of all systems is predicated on an adequate and continuous water supply.

(*e*) Steel or reinforced-concrete hinged shutters are the most effective shields against blast at wall openings, but steel-roller shutters are recommended at openings in interior walls.

(*f*) Steel stacks below 75 feet in height are easily erected and repaired but reinforced-concrete stacks are more resistant to blast forces. Stacks over 100 feet high should be round and constructed of reinforced concrete or reinforced brick.

(*g*) Machine tools in Hiroshima were least liable to serious blast and debris damage in lightly sheathed, steel-frame buildings and most liable to serious damage in load-bearing, brick-wall buildings. The three types of bomb-resistant construction suggested in paragraph (2) above would be equally satisfactory for housing machine tools except that in frame construction the machines would require strong foundation anchors to prevent overturning from mass building distortion and blast forces.

N. PHOTOGRAPHIC INTELLIGENCE

1. Damage Evaluation

The damage to Hiroshima resulting from the atomic-bomb attack of 6 August 1945 is the subject of a report issued by the Physical Vulnerability Section of the Joint Target Group. The report was based on a study of photographic sortie 3 PR–5M391 of 9 August 1945. The following paragraphs indicate the reliability of the report.

a. The location of ground zero, as estimated by the Joint Target Group report, was approximately 1,130 feet to the northeast of the actual ground zero. The reported probable degree of error was plus or minus 500 feet.

b. The 4-square-mile area of virtually total destruction reported by the Joint Target Group is substantially correct. One small area of additional damage (0.048 square mile) was beyond the limits of the photographic coverage avilable for the report.

c. It is impossible from vertical photographs to assess internal damage to buildings, the roofs of which remain intact, and no attempt was made to do so in the Joint Target Group report. It is felt, however, that it will be of interest to show the figures since practically all concrete buildings within the badly damaged area of the city did suffer internal damage from fire.

Damage to contents

Number of buildings	Fire damage to contents (percent)
39	100
15	50–100
3	0–50
17	0

NOTE.—All but 6 buildings were within the burned area.

d. Functional identifications were given to 67 annotated installations, 51 of which were checked by this team.

Functional identification

	Number of installations	Percentage of total
Identified correctly	26	50. 9
Identified incorrectly	11	21. 6
Given similar identification	4	7. 9
Unidentified by P. I. report	10	19. 6
Total	51	100. 0

e. The MAE of a weapon is the probable area of a specified type and degree of damage which would result, if the weapon were used against an area of unlimited extent, completely built up with targets of the specified type and construction. The Joint Target Group reported the MAE for superficial damage to average single and multistory buildings to be 10.7 square miles with the Hiroshima atomic bomb. The MAE's of this bomb for structural damage about GZ determined by the team are as follows:

Building classifications	MAE's in square miles	Radii in feet
Multistory, earthquake-resistant	0. 03	500
Multistory, steel- and reinforced-concrete frame (including both earthquake and non earthquake-resistant buildings)	. 05	700
1-story, light, steel-frame	3. 4	5, 500
Multistory, load-bearing, brick wall	3. 6	5, 700
1-story, load-bearing, brick wall	6. 0	7, 300
Wood-frame industrial-commercial (dimension-timber construction)	8. 5	8, 700
Wood-frame domestic buildings (wood-pole construction)	9. 5	9, 200
Residential construction	6. 0	7, 300

Since the reported MAE was figured for *superficial* damage and this team's MAE's were for *structural* damage no direct comparison of the two can be made. Moreover, many of the buildings (particularly the wood-pole and wood-frame, industrial-commercial types of construction) reported by Joint Target Group as being of V3 and V4 vulnerability (Reference tables) were found to be much more vulnerable than Occidental buildings included in those categories.

2. Value of Photo Intelligence to Ground Survey

In Hiroshima there was frequent difficulty in establishing the cause of damage since a typhoon and floods ravaged the city a few weeks following the atomic-bomb attack but before the survey team arrived on the scene. Photographs taken in the interval between the dates of the attack and the typhoon were often used to establish the cause of damage when reliable ground information was lacking.

a. When, as often happened, interrogation brought out conflicting statements, photographs were used to help establish the validity of one or the other.

b. Photographs were used to determine routes of travel and for orientation on the field.

c. Firebreaks in existence before the attack were plotted, and isolated areas of damage were located from aerial photographs.

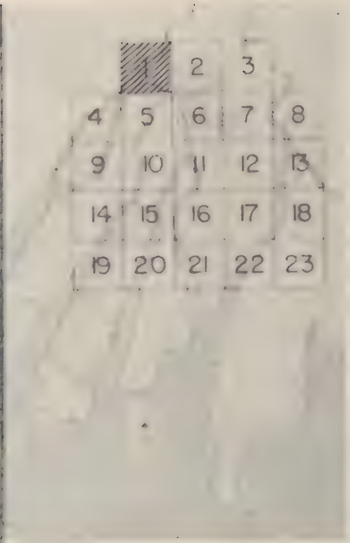
d. It is often impossible or inadvisable for a ground survey to complete a detailed study of the entire damaged area. In such instances a comprehensive damage analysis done from good quality photographs by a competent interpreter will accurately indicate the extent and relative degree of damage. In order to establish the degree of damage in more detail, spot checks can be made throughout the area.


II (PS)
PHOTO
SUMMARY
HIROSHIMA

II-HIROSHIMA-PHOTO SUMMARY
PRE-ATTACK MOSAIC
(UNCONTROLLED)
HIROSHIMA
PHOTOS OF 13 APRIL 1945
0
2000
4000
1000
3000
5000
FEET
PHOTO I-II (PS)
SECRET
SECRET


II - HIROSHIMA - PHOTO SUMMARY
POST-ATTACK MOSAIC
(UNCONTROLLED)
HIROSHIMA
PHOTOS OF 11 AUGUST 1945
0 2000 4000
1000 3000 5000
FEET
PHOTO 2-II (PS)
SECRET
SECRET


AUGUST 11 1945
AERIAL
PHOTOS
(VERTICAL)
APRIL 13 1945



Summary of structural damage

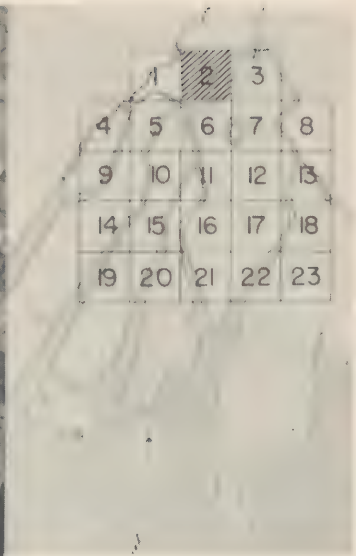
Bldgs.	*Percent*	*Cause*
80	31	Blast
81	None	
Bridges		
40	55	Fire.
50	None	
51	None	

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE



Summary of structural damage

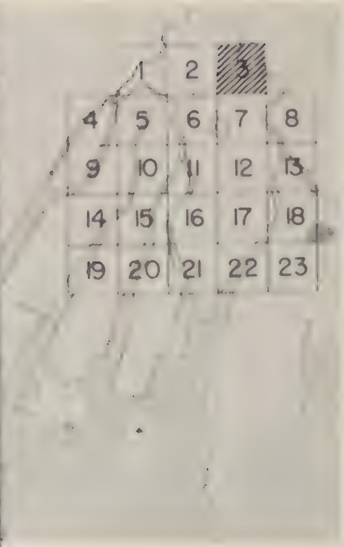
Bldgs.	*Percent*	*Cause*
72	100	Blast.
74	None	
75	None	
76	12	Blast.
77	100	Mixed.
78	50	Blast.
79	69	Fire.
129	None	
Bridges		
25	15	Flood.
26	None	

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE



Summary of structural damage

Bldgs.	*Percent*	*Cause*
70	100	Mixed
Bridges		
10	15	Flood.
11	None	
26	None	

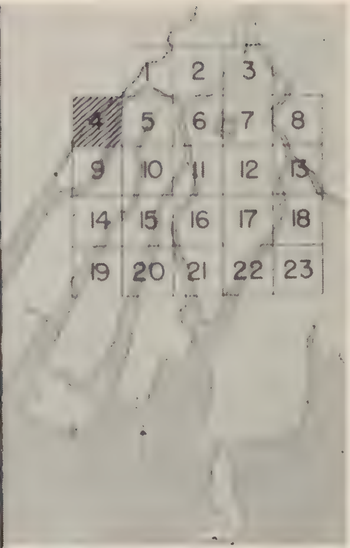
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
None		
Bridges		
41	None	
42	100	Flood
48	None	
49	100	Flood

DATE OF PHOTOS

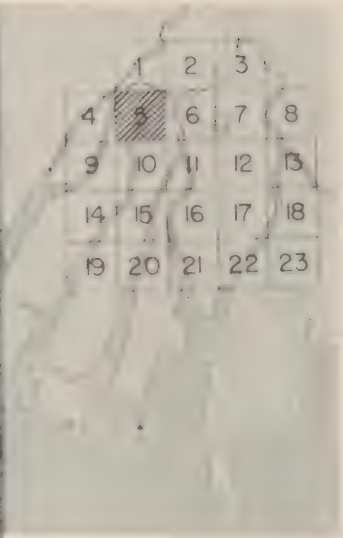
BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000

FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
82	77	Blast
82	27	Blast
84	100	Blast
85	None	
103	None	
105	None	
Bridges		
28	100	Flood
38	100	Fire and flood
39	100	Fire and flood

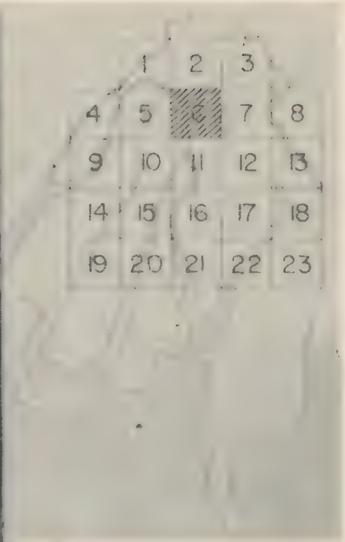
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
67	100	Blast
68A	100	Blast
68B	100	Blast
68C	100	Blast
69	100	Blast
Bridges		
27	None	
28	100	Flood

DATE OF PHOTOS

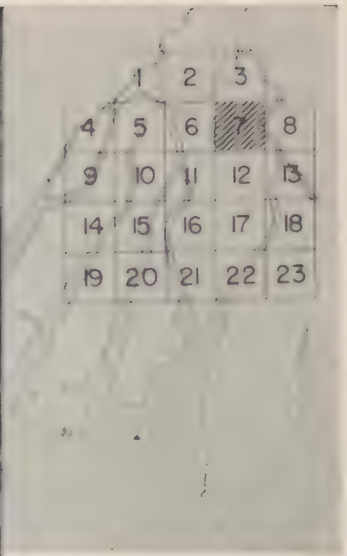
BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000

FEET



Summary of structural damage

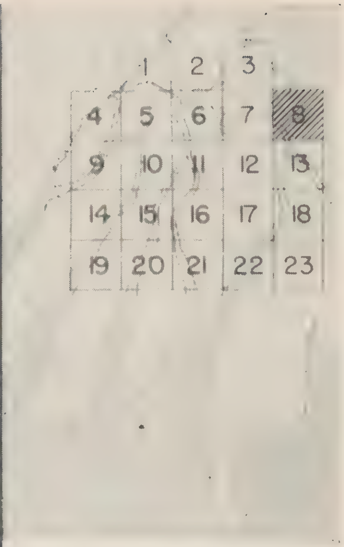
Bldgs.	*Percent*	*Cause*
64	None	
65	None	
66A	100	Blast
66B	100	Blast
66C	100	Blast
66D	100	Blast
Bridges		
8	None	
9	None	

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE



Summary of structural damage

Bldgs.	*Percent*	*Cause*
118	100	Blast

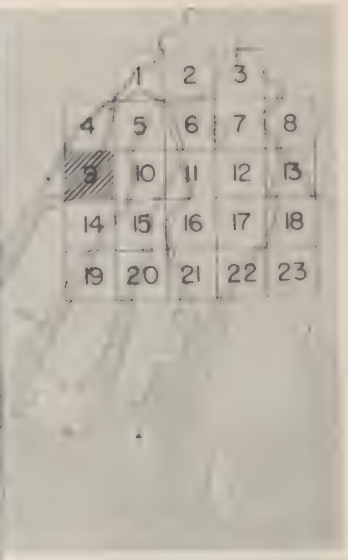
Bridges
None

DATE OF PHOTOS

BEFORE — 13 APRIL 1945
AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
102A	26	Blast
102B	18	Blast
102C	66	Blast
108	100	Blast
Bridges		
43	100	Mixed
44	None	
45	15	Flood

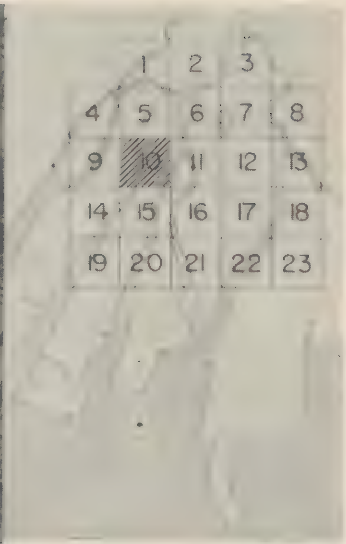
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
86	4	Blast
92	100	Blast
93	100	Blast
107	100	Blast
Bridges		
30	60	Flood
30A	10	Blast
34	100	Fire
35	100	Flood
36	100	Flood
37	55	Flood

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET

Summary of structural damage

Bldgs.	*Percent*	*Cause*
1	41	Blast
2	4	Blast
3, 4, 5	100	Blast
6	None	
7	84	Blast
8	59	Blast
9	21	Blast
10	100	Blast
11	22	Blast
12	69	Blast
13, 14, 17	100	Blast
18	7	Blast
19	9	Blast
20	1	Blast
21	80	Blast
22	8	Blast
23	11	Blast
24	None	Blast
25	6	Blast
41	None	
42, 94	100	Blast
95	1	Blast
96	31	Blast
100	None	
101	100	Blast
Bridges		
22, 23	None	
24	10	Blast
29	100	Blast

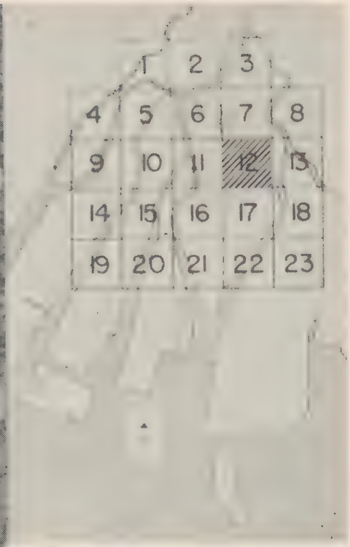
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
38	None	
39	None	
40	None	
44	39	Blast
45	100	Blast
46	100	Mixed
47	None	
48	None	
49	None	
50	None	
51	None	
52	100	Mixed
58	100	Mixed
59	None	
60	100	Mixed
61	None	
62	None	
63	100	Blast

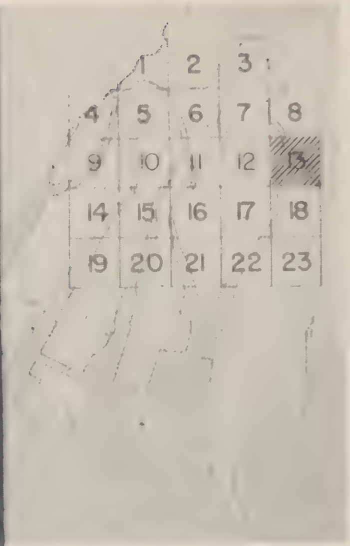
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
110	100	Mixed
120	None	
121	70	Mixed
122	None	
133	None	
134	None	
135	None	
Bridges		
4	None	
5	None	
5A	None	
7	None	
7A	None	
12	None	
13	25	Blast and flood
13A	100	Blast and flood
31	60	Flood

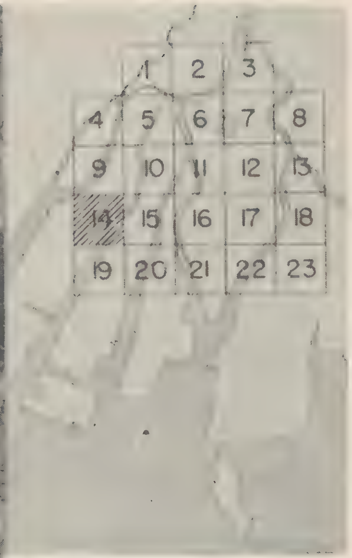
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
None		
Bridges		
33	70	Flood

DATE OF PHOTOS

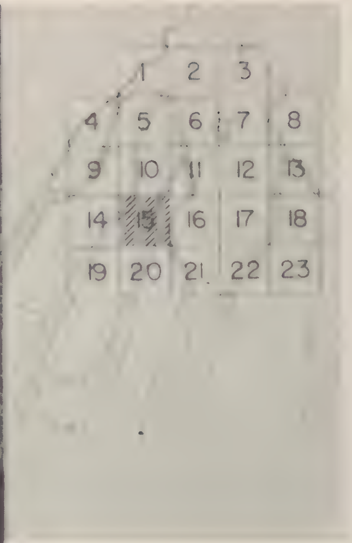
BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000

FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
None		
Bridges		
31	60	Flood

DATE OF PHOTOS

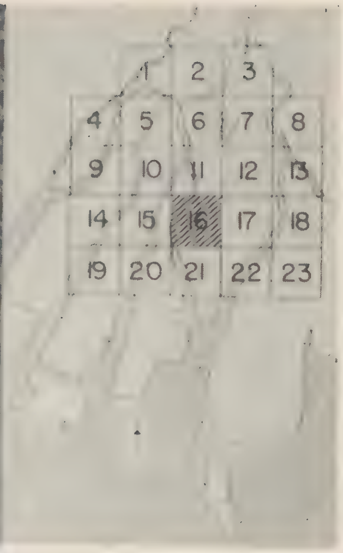
BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000

FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
15	100	Blast
16	None	
26	None	
27	6	Fire
28	None	
29	100	Blast
32E	None	
37	100	Blast
Bridges		
19	None	
20	None	

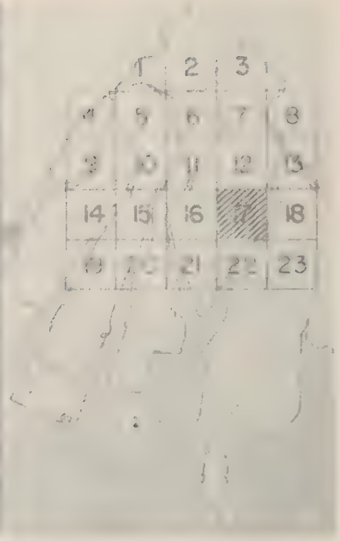
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

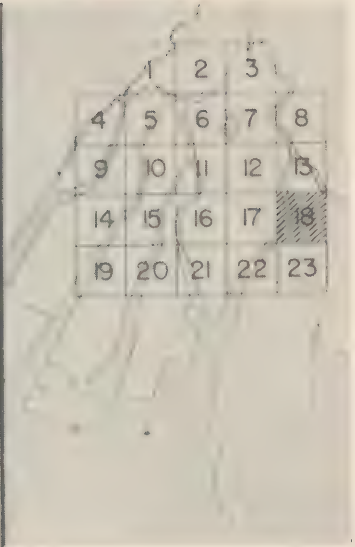
Bldgs.	*Percent*	*Cause*
53	100	Blast
54	100	Blast
55	100	Mixed
56	100	Blast
57	100	Blast
Bridges		
16	None	

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE



Summary of structural damage

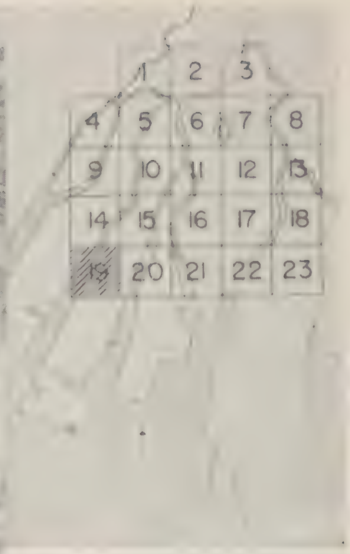
Bldgs.	*Percent*	*Cause*
111	100	Blast
Bridges		
15	None	
16	None	

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE



Summary of structural damage

Bldgs.	*Percent*	*Cause*
87A	100	Blast
87B	None	
88	100	Blast
89	None	
Bridges		
32	70	Flood

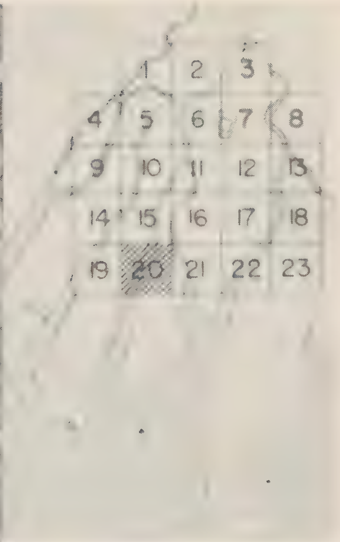
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

Bldgs.	*Percent*	*Cause*
132	50	Fire

Bridges

None

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET

Summary of structural damage

Bldgs.	*Percent*	*Cause*
30	100	Blast
31	None	
32A	None	
32B	None	
32C	100	Mixed
33	None	
34	100	Mixed
97	100	Blast
98A	50	Blast
98B	None	
99	100	Blast
Bridges		
18	None	

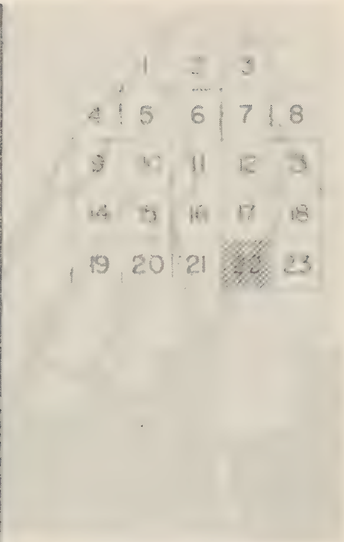
DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

0 250 500 750 1000
FEET



Summary of structural damage

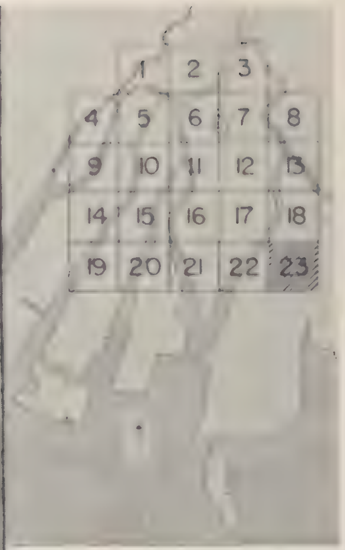
Bldgs.	*Percent*	*Cause*
32D	None	
32H	None	
35A	None	
35B	None	
36	27	Blast
112A	34	Blast
112B	None	
112C	100	Blast
112D	100	Blast
112E	63	Blast
113A	100	Blast
113C	None	
113D	None	
113E	None	
113G	100	Blast
128	100	Blast

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE



Summary of structural damage

Bldgs.	*Percent*	*Cause*
116A	None	
116B	None	
116E	None	
116H	3	Blast
116I	3	Blast
Bridges		
None		

DATE OF PHOTOS

BEFORE — 13 APRIL 1945

AFTER — 11 AUGUST 1945

PHOTO SCALE

10
7
8
4
5
1
11
3
9
6
2
12
GROUND
PHOTOS

PHOTO
1–II (PS)

PHOTO
2–II (PS)

PHOTO
3–II (PS)

PHOTO
4–II (PS)

PHOTO
5–II (PS)

PHOTO
6–II (PS)

PHOTO
7–II (PS)

PHOTO
8–II (PS)

PHOTO
9–II (PS)

PHOTO
10–II (PS)

PHOTO
11–II (PS)

PHOTO
12–II (PS)

SECTION III

GENERAL INFORMATION

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Dates of survey	62
PDD Field Team 1	62
Scope of investigation	62
Acknowledgment	62
Difficulties encountered	62
Favorable factor	63
Source of data	63

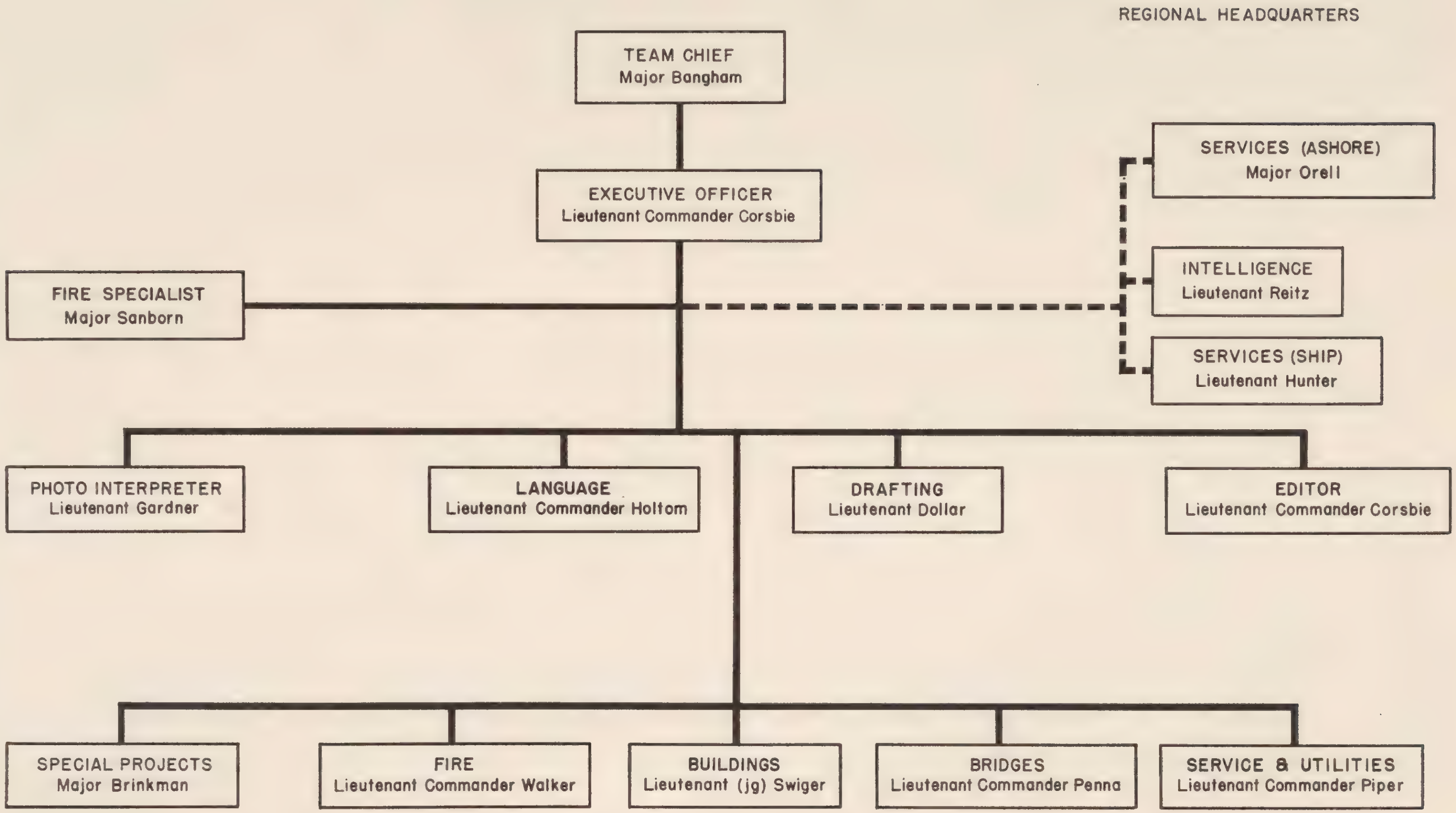
UNITED STATES STRATEGIC BOMBING SURVEY

Physical Damage Division Team 1

Hiroshima, Japan

ORGANIZATION CHART

14 October 1945 to 26 November 1945



1. Dates of Survey

The survey of Hiroshima was started on 14 October 1945 and completed on 26 November 1945.

2. PDD Field Team 1

Physical Damage Division Field Team 1 consisted of the following personnel:

- Maj. J. F. Bangham, Jr., AC, team chief.
- Maj. E. A. Brinkman, CE, chief engineer.
- Maj. F. J. Sanborn, AC, fire study.
- Maj. J. M. Wolverton, AC, fire engineer.
- Lt. Comdr. R. L. Corsbie, CEC, executive officer, architect.
- Lt. Comdr. J. H. Holtom, S (I), language.
- Lt. Comdr. N. C. R. Penna, CEC, civil engineer.
- Lt. Comdr. G. P. Piper, CEC, civil engineer.
- Lt. Comdr. C. B. Walker, S (A), fire engineer.
- Lt. E. G. Dollar, A, architect.
- Lt. J. W. Gardner, A, photo interpreter.
- Lt. J. F. Garrison, Jr., A, photo interpreter.
- Lt. H. C. Montgomery, Jr., A, photo interpreter.
- Lt. (jg.) L. W. Galloway, S (O), ordnance specialist.
- Lt. (jg.) W. F. Swiger, A, civil engineer.
- Mr. E. M. Hall, civilian, language.
- J. A. Meuenster, ChPhoM, photographer.
- E. G. Anderson, SF2/c, draftsman.
- J. P. Harmon, Y2/c, yeoman.
- C. R. Adamson, Jr., PhoM3/c, photographer
- H. Fagin, S (X) 3/c, draftsman.
- C. A. Schmeider, Y3/c, yeoman.
- E. W. Waller, S (P) 3/c, draftsman.
- Cpl. J. J. Delaney, photographer.
- Cpl. T. K. Matsuura, interpreter.
- Cpl. K. B. Van Beukering, photographer.
- C. Y. Cain, S1/c, draftsman.
- Pfc. C. A. Cramer, photographer.
- Pfc. G. E. Curtis, photographer.
- Pfc. R. D. Hall, photographer.

3. Scope of Investigation

Physical Damage Team 1 was concerned only with the assessment of physical damage to Hiroshima and, except where judged pertinent to the report, did not attempt to study any other effects of the atomic bomb such as medical aspects, effect upon morale or civilian defense. The team confined itself to the study of buildings, machine tools, bridges, utilities, services, fire damage, stacks; the gathering of intelligence data; and the interrogation of witnesses and city officials. Members of the team also conducted surveys of the physical damage to the city of Ube and the oil refinery at Otake.

4. Acknowledgment

Hiroshima was within the zone occupied by the United States Army Tenth Corps and Forty-first Division, through which clearance had to be made before the survey could be begun. They furnished valuable aid and information which greatly facilitated the survey.

5. Difficulties Encountered

The difficulties that confronted the team in attempting to ascertain the facts in connection with the extent of damage to Hiroshima were important:

a. Summer through fall is the typhoon season in Japan and Hiroshima received a full share of damage from these storms. On 17 September floods developing from torrential rains washed out bridges and caused extensive additional damage to the already stricken city. Again on 5 October the typhoon which swept up from the Ryukyu island chain took its toll of bridges and other installations. This made interrogation the principal method by which differentiation between bomb damage and flood damage could be checked.

b. Almost all records and data in the city proper were either burned by the fires following the dropping of the atomic bomb or were lost in the subsequent floods. As a consequence few records were obtained and those found were usually discovered in the possession of companies located outside the damaged areas. Others were prepared by individual persons upon the request of team members.

c. By the time the team arrived in the field many persons who had escaped from the city immediately after the explosion had returned to their former homes and were constructing temporary residences on the sites. Consequently, survey personnel found flimsy wooden and corrugated-iron shelters interspersed among the remains of the former structures.

d. Attempts to interrogate witnesses who were actually in the city when the disaster occurred were made difficult by the extremely high loss of life and by the immediate dispersal of survivors to the outlying areas. Although many persons volunteered information, it was established by questioning that very few of them had actually been in the city at the time of the detonation. Moreover, it was difficult to trace specific persons

as possible sources of information, since they had either been killed or no record of their whereabouts was available.

e. The work of the team was handicapped to some extent by official regulations governing the movements of the U. S. S. *Sims*, which, although serving as a headquarters ship for the survey, was unable to anchor in Hiroshima Harbor as had been originally planned. Although the passage into Kure Harbor and Hiroshima Bay had been swept by Japanese minesweepers the U. S. S. *Sims* was not permitted to anchor in Hiroshima Harbor, as the United States Navy had not declared the area open to American vessels. Anchoring in Hiro Bay, which offered the closest utilizable landing area, and driving from there into Hiroshima entailed a 3½-hour round trip by small boat and jeep. Therefore, the actual working day in the field began at 0930 hours and ended at 1600 hours.

f. Considerable work in connection with field notes was accomplished on board the U. S. S. *Sims*, but quarters were so cramped that the actual work of writing the report was necessarily delayed until the team returned to the United States.

6. Favorable Factor

A factor which contributed to the efficiency of the survey was that the city of Hiroshima had been declared off limits to American troops. Toward the end of the survey the city was opened to military sightseeing tours, but these were all nonstop and nonalight. This enabled field teams to have a relatively free hand in conducting investigations.

7. Source of Data

Data obtained by the team members were gathered from plant, city, and prefectural records and reports; records drawn up by officials in the city, interrogation, photographs, visual observation, and records obtained from main offices of companies that had branches in Hiroshima. It is the opinion of the members of the team that the information gathered is accurate and reliable.

SECTION IV

THE TARGET

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1. Geographical Description

a. Hiroshima (lat. 34°24′ N., long. 132°28′ E.), first urban target for an atomic bomb, was the seventh largest city in Japan and was located in the southwestern portion of the Island of Honshu on the shore of the Inland Sea.

b. The Inland Sea had long been important to Japan on three scores: (1) as a calm and safe water lane interconnecting Honshu, Shikoku, and Kyushu, (2) as a protected anchorage area for naval and merchant vessels; and (3) as one of the most beautiful scenic areas in the world. The southern portion of Honshu which faced the Inland Sea was called Sanyo, or "sunny side of the mountains," indicating the prominence and respect attached to the area by the Japanese. Hiroshima was centrally located along this Sanyo coast.

c. The whole of Japan was divided into eight administrative regions, called Chiho Gyoshi. The entire southwestern section of Honshu, beyond the area encompassing Kobe, Osaka, and Kyoto, forms the Chugoku Chiho, or middle kingdom region, the administrative center of which was Hiroshima. Among the places of importance in the Chiho were: Kure, the great naval base, less than 20 miles from Hiroshima; Shimonoseki, the Honshu terminus of the Kammon Tunnel; Matsue and Tottori, on the Japan Sea; and Okayama, Fukuyama, Onomichi, Iwakuni, Yamaguchi, and Ube, on the Inland Sea. The Chugoku Chiho had neither high mountains nor extensive lowland plains, but was uniformly rugged country, with steep hogback ridges and chasm-like valleys cut by small, swift streams. Most of the cities were built along the coast at the mouths of streams where silt flats had formed.

d. The Chugoku Chiho comprised five prefectures (Ken), one of which was Hiroshima Prefecture, centrally located on the Inland Sea coast. Kure and Hiroshima were the primary cities in the prefecture, the latter being the administrative center of the prefectural government. The Ota River, rising in the mountains, flowed generally east through the western section of the prefecture, thence southward into the Inland Sea at Hiroshima Bay. In the valley of the lower reaches of the river, alluvial deposits had formed which provided sites for small towns, and, at the mouth of the river, deltaic islands were the site for the city of Hiroshima. Westward and southward from the mouth of the Ota along the precipitous shorelines were a few small residential and fishing villages. Southwest of Hiroshima, 20 miles offshore, was the island of Miyajima, one of the scenic spots of Japan, a mecca for pilgrims and of interest to tourists because of the famous temples, shrines and scenery. Eastward from Hiroshima along the coast were several towns, the closest being Kaitachi, Kure and Hiro, the latter being an extensive and well equipped naval base, were about 18 miles distant; and Fukuyama and Onomichi were farther along the coast in the eastern section of the prefecture.

e. The Ota River delta was made up of six islands separated by the channels of the river. Except where small rocky islands no more than 700 feet high, previously offshore, were surrounded by the silt deposits, the islands were uniformly flat, and about 10 feet above mean low water. The natural deltaic formations had been extended by dredging and filling operations to satisfy the needs of a growing city, and, consequently, the southern (or seaward) extremities were more regular in shape. It is on these islands and on the flats along the mainland river banks that the city of Hiroshima was located, surrounded by steep, wooded rises except to the south where it faced the Inland Sea.

2. Climate

a. In general, an oppressively hot and humid summer and a mild winter characterized the climate of Hiroshima. The mean annual temperature was 57.9° F., which is about the same as that of Baltimore, Md.

b. The latter parts of April and June and the entire month of September were the rainy seasons. The amount of snowfall during the winter was negligible.

c. Light, warm, southerly winds blew from May through October, and northerlies and westerlies prevailed during the remainder of the year. The typhoon season was June through October. These storms were particularly active during the month of September, when winds ranging up to 75 miles per hour occurred, often accompanied by torrential rains and floods.

3. Historical Background

a. Originally a small fishing village at the mouth of the Ota River, Hiroshima's history really began when Terumoto Mori in 1591 became feudal lord of the region including most of what is now the Chugoku Chiho. Under his direction the Castle of Hiroshima was begun and completed in 1594. The erection of the castle assured the

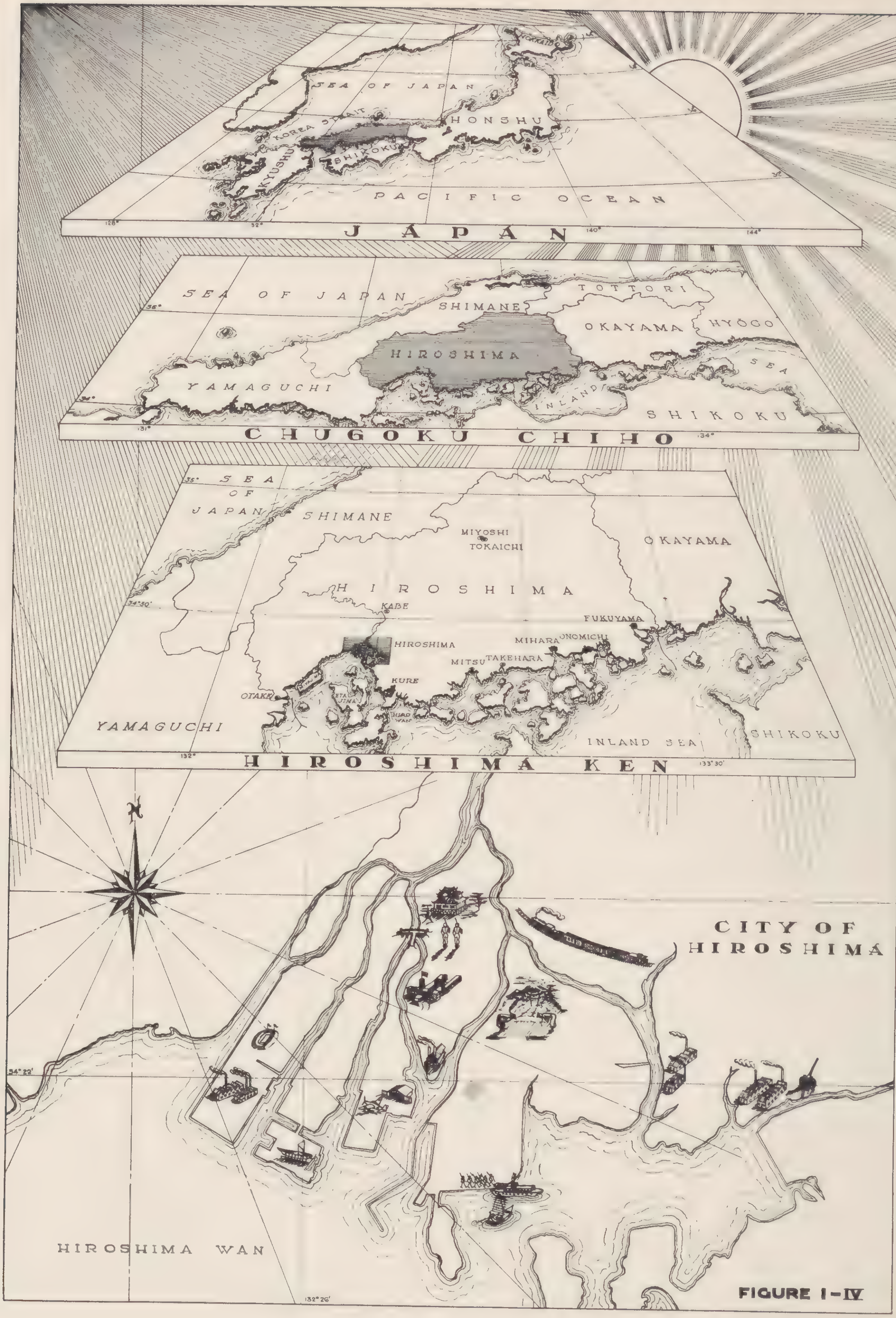
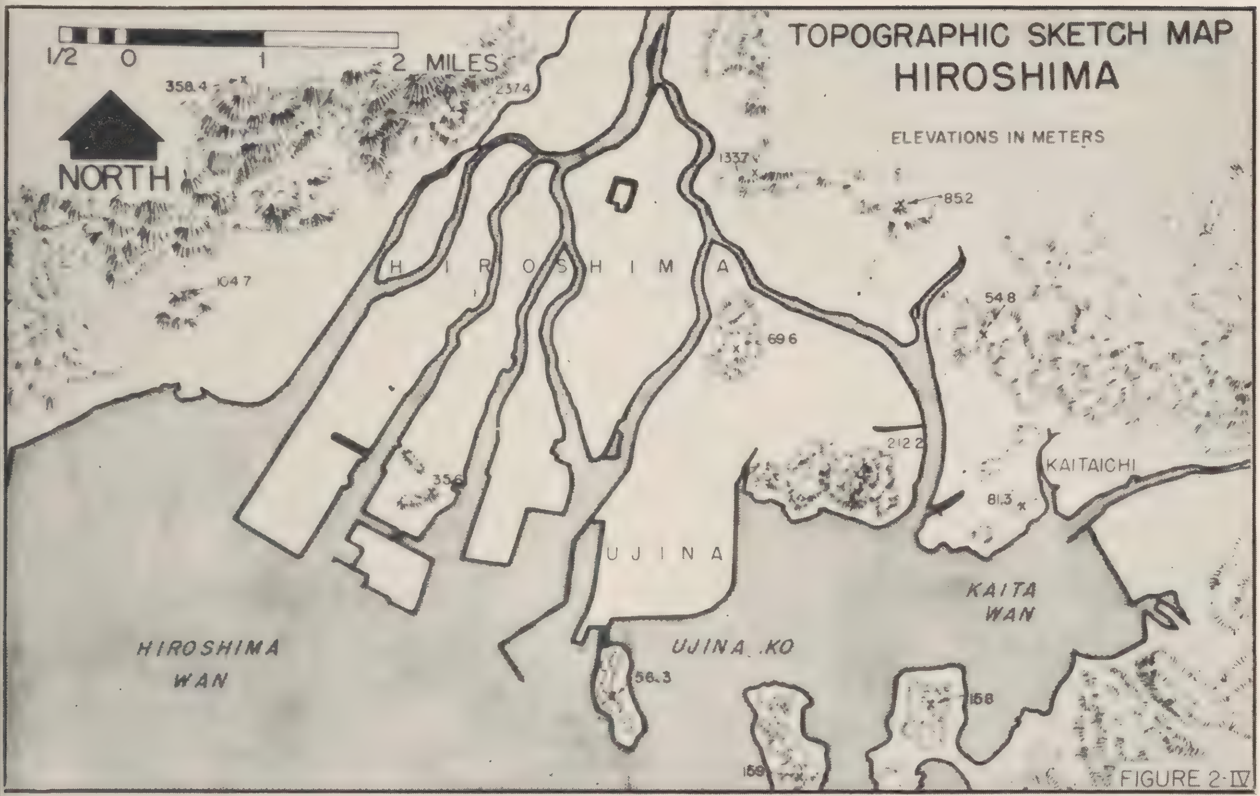

SEA OF JAPAN
KOREA STRAIT
HONSHU
KYUSHU
SHIKOKU
PACIFIC OCEAN
JAPAN
SEA OF JAPAN
TOTTORI
SHIMANE
OKAYAMA
HYOGO
HIROSHIMA
YAMAGUCHI
INLAND SEA
SHIKOKU
CHUGOKU CHIHO
SEA OF JAPAN
SHIMANE
MIYOSHI
TOKAICHI
OKAYAMA
HIROSHIMA
KABE
FUKUYAMA
ONOMICHI
MIHARA
HIROSHIMA
TAKEHARA
MITSU
KURE
OTAKE
YAMAGUCHI
INLAND SEA
SHIKOKU
HIROSHIMA KEN
CITY OF HIROSHIMA
HIROSHIMA WAN

FIGURE I-IV


TOPOGRAPHIC SKETCH MAP
HIROSHIMA
ELEVATIONS IN METERS
1/2 0 1 2 MILES
NORTH
358.4
237.4
133.7
85.2
104.7
H I R O S H I M A
69.6
54.8
212.2
KAITAICHI
35.6
81.3
U J I N A
KAITA
WAN
HIROSHIMA
WAN
UJINA KO
56.3
158
159
FIGURE 2-IV

expansion of Hiroshima from a village into a castle town on the delta below the castle. With the reestablishment of the Tokugawa clan as shoguns of the empire in 1603, Hiroshima castle was taken over by the Fukushimas. In 1619 it passed into the hands of the Asano family, who remained as hereditary chiefs of the castle and lords of the region until the Meiji Restoration in 1868.

b. The feudal castle was built on the delta at the mouth of the Ota River and the castle town grew up south of it along the thoroughfare, which cut across the deltaic islands, connecting Kyoto and Shimonoseki. Hiroshima gradually came to assume importance as a communication center because of its position on the Inland Sea and along the Sanyo highway and subsequent railroad. The deltaic formations were extended to make more room for the growing town and to enable cultivation of more farm land to feed the increasing population. During the first 100 years that the Asano family was in possession of the region, the land acreage under cultivation was doubled. Since that time there have been periodic reclamation and expansion projects, the latest having been under way at the time of the atomic-bomb attack.

c. The establishment of the prefectural government by the Emperor Meiji in 1868 marked the beginning of Hiroshima's development into a modern city. More farm land on the delta was taken over for use as residential and industrial sites. The delta was again extended to provide more land, particularly toward the island of Ujina, thereby connecting Hiroshima to an adequate harbor area.

d. In the sixth year of the Meiji Restoration a military garrison was first established at Hiroshima, but it was during the Sino-Japanese War (1894–95) that the city began to assume importance as a military center. The Emperor Meiji made the castle his residence and general staff headquarters during that campaign on the Asiatic mainland. The city later served as headquarters for the Japanese "Ever Victorious Fifth Army," which conquered Singapore, and the Second General Army. At the time of the atomic-bomb attack there were 24,158 of the Army and 58 of the naval forces stationed in the city.

4. General Description of the Modern City

a. The brief history of the city of Hiroshima shows how it had its origin in a small castle town on the northern end of the deltaic islands at the mouth of the Ota River and increased in size with the natural and man-made extensions of the islands. The street pattern, the built-upness, and the zone occupancy of the modern city reflected its historical growth.

b. In general, the street pattern was an irregular block plan with variations imposed by the logical flow of interisland traffic and the irregular shapes of the islands. A large portion of the northern half of the principal island was taken up by the old castle grounds, and the southern portions of most of the islands were used for industrial and military purposes. The portions of the three central islands immediately south of the castle grounds comprised the commercial district wherein most of the multistory office and commercial buildings were located.

c. The bulk of the newer commercial and government structures was representative of post-1923 Japanese construction. These buildings were relatively modern in plan and design and were substantially constructed. The older structures of similar occupancy were more classical in appearance and were usually of wall-bearing construction. Interspersed among these buildings were the low, flimsily built shops and offices of typical Japanese design and structure. Except for the more modern factories, which were built during or immediately prior to the war and which reflected occidental influence, the industries were housed in exceedingly vulnerable frame or wall-bearing units scattered throughout the city. Most of the remaining flat area in the city was compactly built up with typical Japanese residential or residential-commercial, one-story, wood buildings.

5. Social Conditions

a. The city was badly overcrowded, with over 31,600 persons per square mile, which is approximately 1.23 times the average density for the 5 boroughs making up greater New York City, despite the fact that almost all residences in Hiroshima had only 1 or 2 stories. This population density was largely attributable to the geographical limitations imposed by the islands and to the fact that such a large percentage of utilizable land area within the city was monopolized by the Army.

b. From 1888, when the first census recorded 84,873, to June 1942, when the peak population of 380,000 was reached, the city steadily grew in

civilian population, and coincidentally increased in in physical size with the reclamation of land and the incorporation of suburban communities under the city government. As the probability of aerial attack became more evident, the civilian pouplation had been decreased to approximately 245,000 as of 5 August 1945, the day before the attack, due to voluntary and government-planned evacuation.

6. Economic Conditions

a. The city of Hiroshima was unique among the sizable urban communities in Japan in that the bulk of its workers was dependent upon employment in civil and military governmental agencies and small and moderate-sized private enterprises which directly performed services required by these agencies. Since the Chugoku district did not produce enough hydroelectric power, coal, or iron to support heavy basic industry, Hiroshima had few large industries. Since only 20 percent of the Ujina Harbor facilities was available for other than military purposes, relatively little trade was possible. What surplus of foodstuff was raised in the locality was largely disposed of to the Army procurement agencies and shipped by them. Because of the absence of industry and large-scale trade, bank deposits in the city scarcely went beyond petty, middle-class savings, insufficient as commercial or industrial capital to accelerate active enterprises.

b. Some concerns with main offices in other cities of Japan had established subsidiary branch factories in Hiroshima. Such were the Japan Steel Works, Toyo Industries, Mitsubishi Industries, all relatively new plants, Banks, department stores, railroad, newspapers, and numerous other small industrial and commercial establishments gave employment to many.

7. Public Utilities

a. Electricity. Electricity for lighting and industrial purposes was furnished by the Chugoku Electric Co., which obtained it from Nippon Electric. The Japanese reported that all houses in the city were equipped with electric lighting.

b. Gas. The Hiroshima Gas Co. manufactured and distributed producer gas for domestic and industrial purposes. Approximately 75 percent of the residences received service.

c. Water. Hiroshima had an adequate municipal water supply system for both industrial and domestic use, due largely to Army influence. Water was taken from the Ota River, purified, and distributed to all sections of the city at the rate of 50 gallons per person per day, which, although approximately one-half of the usual United States quantitative standard, was sufficient by Japanese standards.

d. Sewage. As a result of the oriental custom of using night soil as fertilizer, no sanitary sewers were necessary. Hiroshima had an adequate storm-water sewer system into which domestic waste water was drained.

8. Railroads (Fig. 3–IV)

Hiroshima was one of the principal intermediate stations on the Sanyo main line of the government railway system running along the Inland Sea from Kyoto to Shimonoseki, one of the most vital links in the Japanese railway networks. A feeder line from Kure joined the main line at Kaitaichi. Connecting with the Sanyo line at the East Hiroshima railroad yards were the branch line to Ujina and the Geibi line which extended northeast into the interior of the prefecture. The Kabe electric railroad line ran northward along the Ota River from the Yokogawa Station in Hiroshima. One indication of the importance of Hiroshima as a rail center was the fact that an average of 6,000 freight cars per month were shuttled through the yards between 1941 and 1945. The yards included roundhouse and engine house facilities.

9. Highways (Fig. 3–IV)

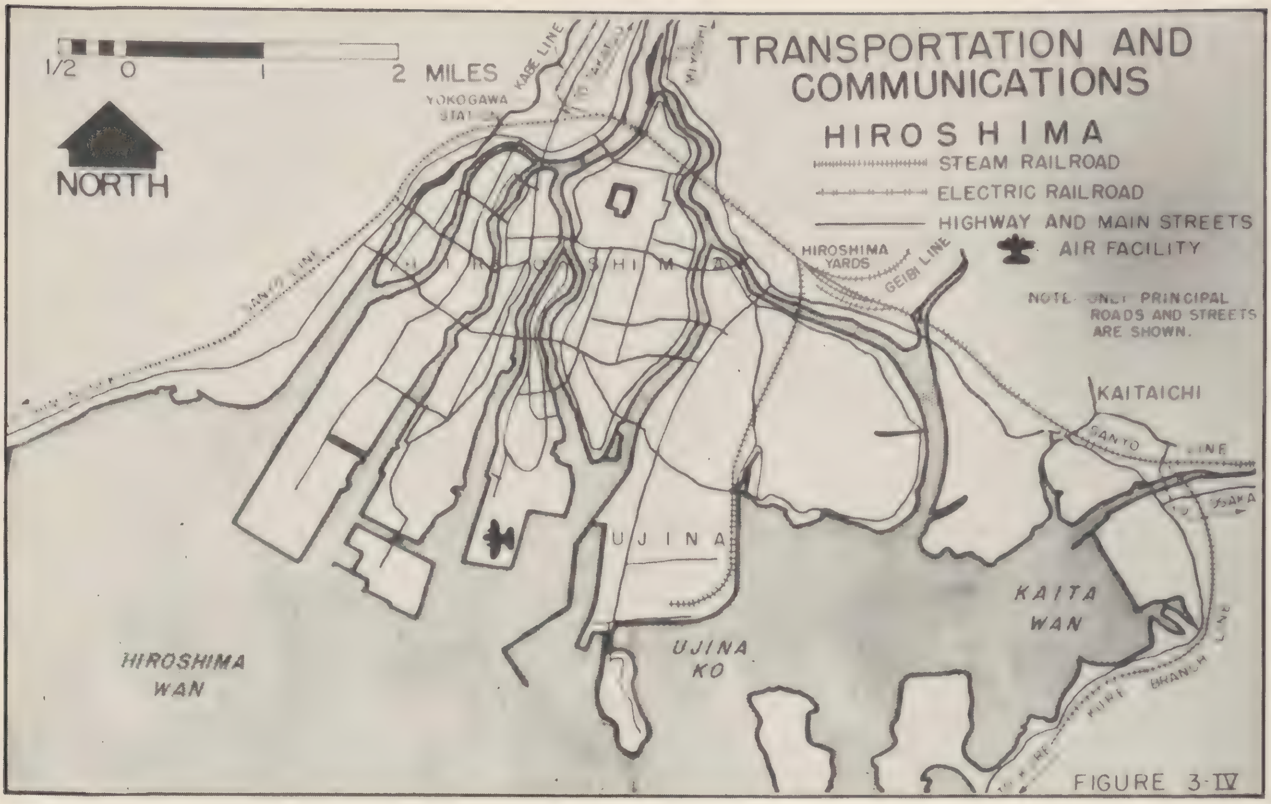
The main highway between Osaka and Shimonoseki followed generally along the Sanyo railroad route and crossed the Ota River delta at Hiroshima. Another good highway followed along the coast to Kure. Secondary roads, not suitable for extensive motor traffic, followed northward along the valley and interconnected the small hinterland towns and Hiroshima.

10. Streets and Bridges (Fig. 3–IV)

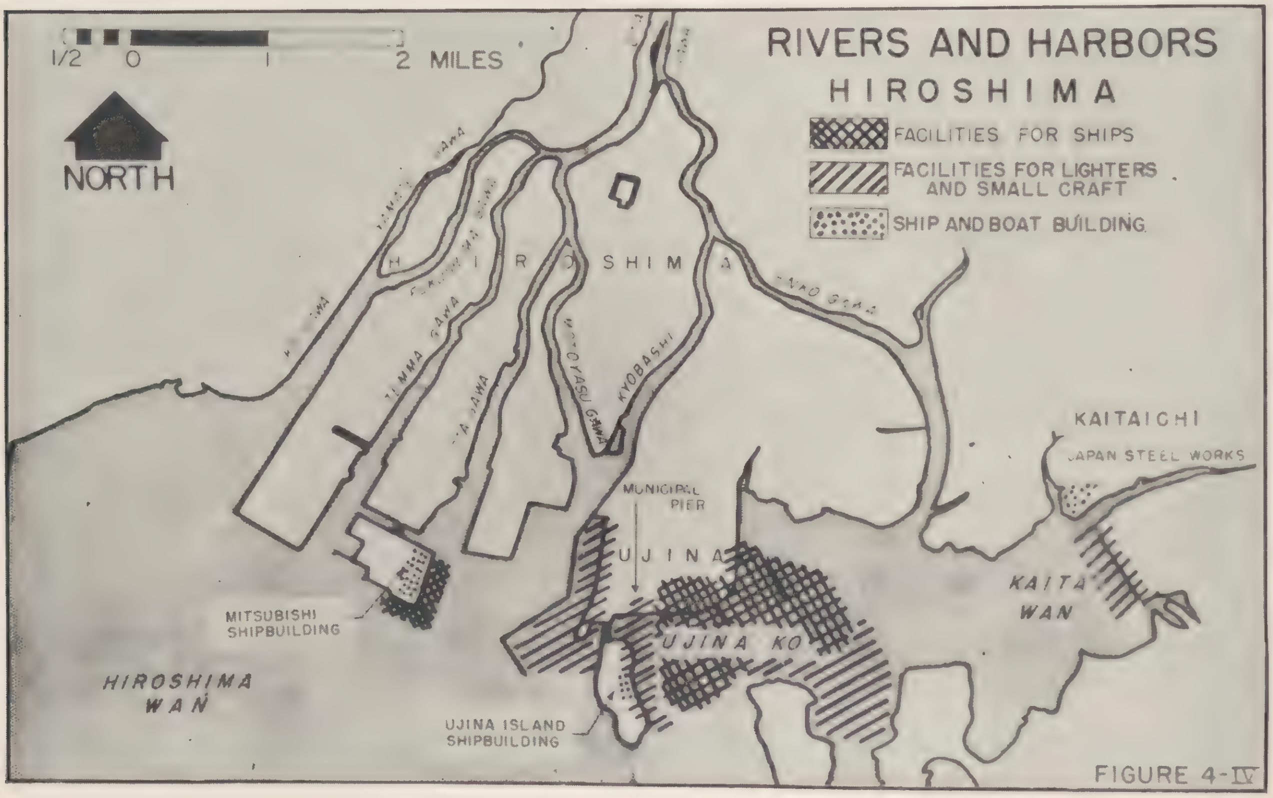
One of the principal features of the street system in Hiroshima was the 45 highway bridges which were necessary to connect the islands on which the city was built. Principal streets were wide enough for 2 to 4 lanes of traffic; secondary streets were wide enough for 1 to 2 lanes; and almost all streets were paved.

11. Street Railway and Busses

The Hiroshima Electric Railway Company furnished both streetcar and bus transportation to all sections of the city and most outlying towns. The service was only fair by comparison with that provided in most American cities and equipment was largely outdated.



TRANSPORTATION AND COMMUNICATIONS
HIROSHIMA
STEAM RAILROAD
ELECTRIC RAILROAD
HIGHWAY AND MAIN STREETS
AIR FACILITY
NOTE: ONLY PRINCIPAL ROADS AND STREETS ARE SHOWN.
1/2 0 1 2 MILES
NORTH
KABE LINE
YOKOGAWA STATION
SANYO LINE
HIROSHIMA
HIROSHIMA YARDS
GEIBI LINE
KAITAICHI
UJINA
KAITA WAN
UJINA KO
HIROSHIMA WAN
KURE BRANCH LINE
FIGURE 3-IV



RIVERS AND HARBORS
HIROSHIMA
FACILITIES FOR SHIPS
FACILITIES FOR LIGHTERS AND SMALL CRAFT
SHIP AND BOAT BUILDING
1/2 0 1 2 MILES
NORTH
HIROSHIMA
TEMMA GAWA
KYOBASHI
KAITAICHI
JAPAN STEEL WORKS
MUNICIPAL PIER
UJINA
KAITA WAN
UJINA KO
MITSUBISHI SHIPBUILDING
HIROSHIMA WAN
UJINA ISLAND SHIPBUILDING
FIGURE 4-IV

12. Air Facilities

A secondary military airfield and small seaplane base were located on reclaimed land on the southerly end of one of the deltaic islands.

13. Communications

a. Hiroshima was an important communications center primarily because of its important government and military administrative functions. About 9,000 telephones were installed in the city and trunk lines connected with most of the major cities in Japan.

b. Hiroshima was the seat of one of the seven telegraphic bureaus which filtered and censored land telegraph messages; all important cities and towns were connected by the network of lines.

c. A powerful, 10,000-watt radio station, JOFK, and radio-telegraph station, JHL, were important communication instruments for the area.

14. Rivers (Fig. 4–IV)

The rivers, dividing the deltaic islands on which Hiroshima was built, were important as waterways for lighters and small craft which transferred cargo between the shops, warehouses and industries, and ships at anchor in the harbor areas.

15. Ujina Harbor (Fig. 4–IV)

a. Before the harbor at Ujina was developed in 1889 the nearest port for large ships was on the island of Miyajima, 20 miles from the city of Hiroshima. Only the smallest lighters and boats were able to navigate the shallow river channels and come alongside the deltaic islands of the city. During the Meiji Restoration and Hiroshima's new importance as the prefectural headquarters, a total of 340,000 yen was spent to connect the mainland to Ujina Island, to build suitable piers and wharfage, and to dredge and improve the harbor.

b. Although not large, the harbor handled foreign trade amounting to 500,000,000 yen in 1935, and was the major link between Honshu and the Matsuyama area of Shikoku, and, following the Sino-Japanese War (1894–95), was the major embarkation point for troops. The port was never opened to foreign vessels.

16. Shipbuilding

Mitsubishi Shipbuilding Co. fabricating steel cargo vessels of 3,000 tons, and Japan Steel fabricating submersible Army transports (large submarines) were war industries. For many years the Ujina Island Shipyards had built small wooden ships and boats for commercial purposes; during the war they constructed landing craft for the Army.

17. Hiroshima as a Military City

a. Historically, Hiroshima had been important as a military headquarters since the Sino-Japanese War when the Emperor Meiji selected it as a base for continental expeditionary forces and as imperial headquarters. It continued as a port of embarkation throughout the China Incident and World War II. It was the headquarters of the Fifth Army and, in 1945, was made headquarters of the Second General Army which was responsible for the defense of the southwestern section of the Japanese homeland. The military importance of the city can be attributed to three factors: (1) location in the midst of the Chugoku District in a position relatively invulnerable to land and sea attack, (2) good transportation and communication facilities, and (3) protected harbor on the Inland Sea.

b. In addition to the more important and larger areas indicated on the sketch map (Fig. 5–IV), smaller areas of barracks, warehouses, offices and the like, located throughout the city, were controlled by the military. In all, 80 percent of Ujina Harbor facilities and 42 percent of the utilizable land area of the central portion of the city were under the direct jurisdiction of the Japanese Army.

18. Industries (Fig. 6–IV)

In the pre-Meiji era, small-scale industries were developed in the Hiroshima castle town to satisfy the needs of a feudal community. Many of these, such as small boat building, domestic metal casting, rice wine manufacturing, textile and clothing manufacture, still remained in modern Hiroshima. After the Meiji period, meat packing and sewing-needle manufacturing became the most important industries. After World War I, the city took a leading place in the rubber industry and, as World War II began, the ordnance-producing Japan Steel Co., the Toyo Aircraft Industries, and Mitsubishi Machine Tool, Machine and Shipbuilding Industries were developed. Hiroshima, however, never became a highly industrialized city, and, at the time it was attacked with the atomic bomb, there were only three companies employing more than 500 persons. The relative locations of major industries in the city are shown on the accompanying sketch map.

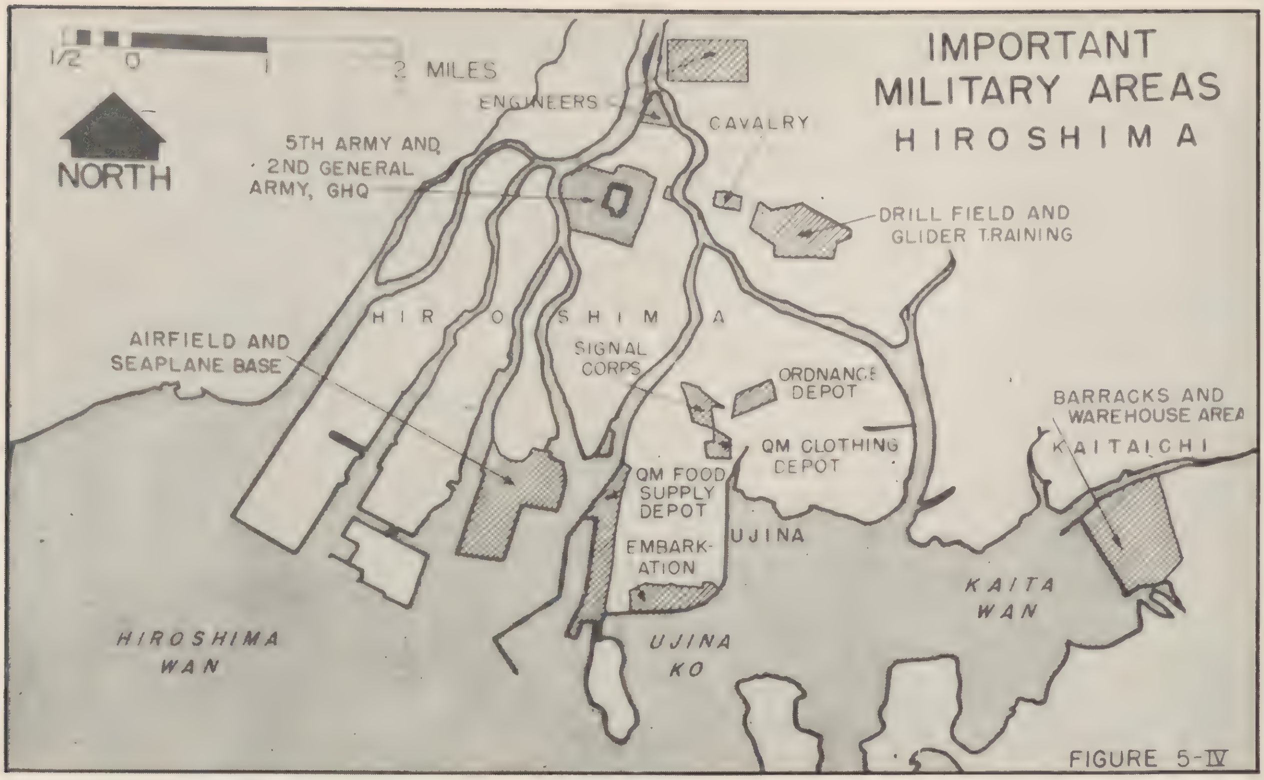


FIGURE 5-IV

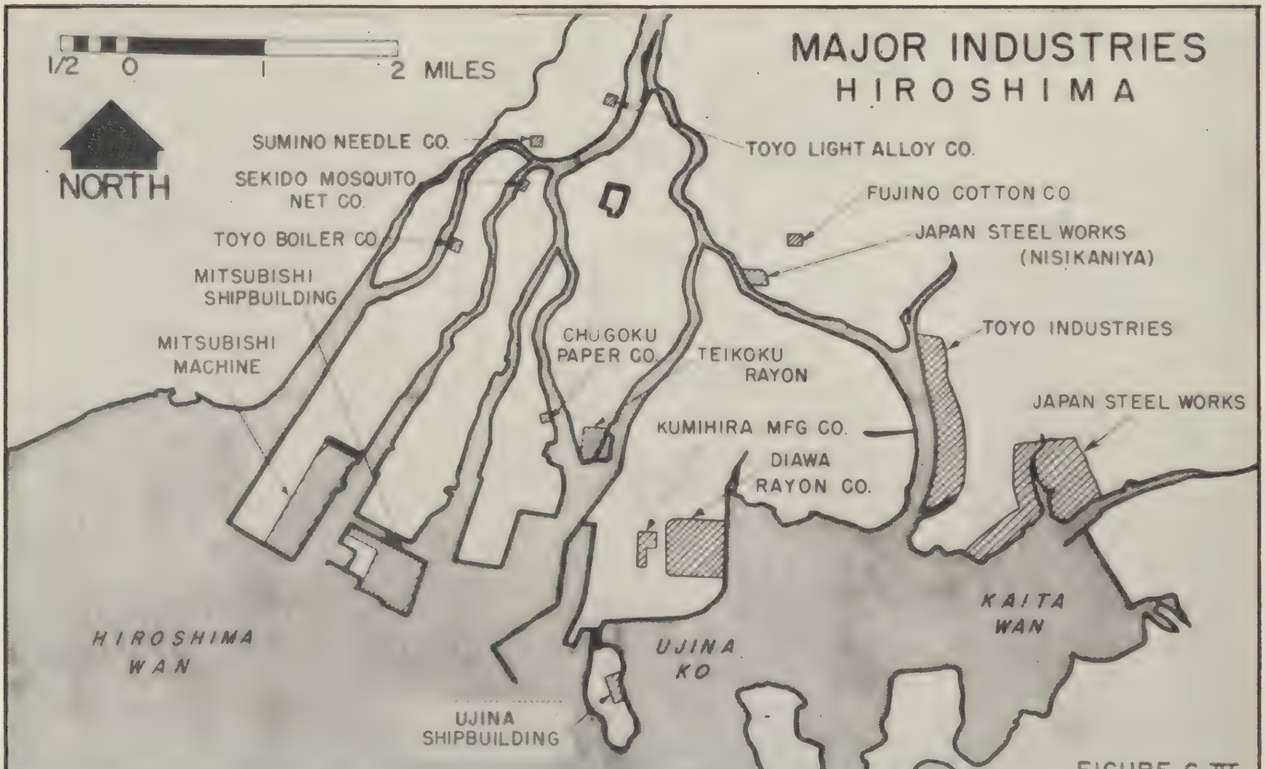


FIGURE 6-IV

19. Government Offices (Fig. 7–IV)

Hiroshima was the administrative seat of the governments of Hiroshima Prefecture, Chugoku District and Shikoku District, as well as the military and commercial center for the area. For that reason, several of the important structures in the city were devoted to office space for the various governmental bureaus. Some of the more important buildings are shown on the sketch map.

20. Hospitals (Fig. 7–IV)

Eight hospitals, including the Red Cross hospital, governmental, military and private hospitals, were within the city limits. The Red Cross hospital and the Communication Bureau hospital were housed in sizable, modern buildings and were well equipped. The military and prefectural hospitals were in wood-frame structures and the remainder consisted of small, private, or special treatment institutions.

21. Schools (Fig. 7–IV)

The Hiroshima University of Literature and Science and Higher Normal School was one of the best known and respected Japanese institutions of higher learning. In addition to the university, 65 other schools, including grammar, middle, high and technical schools, both public and private, were a part of the educational facilities of the city.

22. Photographs

On the following pages are prewar photographs of Hiroshima which give some impression of the built-up density of the city and the types of buildings, parks, and streets which were found there. The photos were probably taken before 1930.

23. Hiroshima as a Target for the Atomic Bomb

It is considered desirable, as an addendum to "The Target," to summarize the physical characteristics of the city of Hiroshima which contributed to or detracted from its value as a target for the atomic bomb:

a. The city of Hiroshima had received only an insignificant amount of prior damage; therefore, what damage resulted could be attributed to the atomic bomb.

b. Being built on a deltaic formation, it was nearly flat for a distance of 6,000 feet in all directions from the aiming point, and for more than 15,000 feet in the southerly quadrant.

c. At various intervals within a 6,000-foot radius from the aiming point there were enough substantially constructed, multistory, commercial buildings of representative structural types to allow comparative study of the effects.

d. Because of the prevalence of wood construction throughout the city, and the pattern of the water courses which formed natural firebreaks, the incendiary effects of the bomb could be analyzed.

e. Within the area were representative types of short-span, fixed bridges in sufficient numbers to permit a relative study of the effectiveness of the weapon against them.

f. Hiroshima was well equipped with public utilities (water, gas, electricity, sewers) and interurban transportation so that conclusions could be drawn regarding the relative vulnerability of these facilities.

g. The principal feature which detracted from the target value was the remoteness of the industrial concentration from the center of the city.

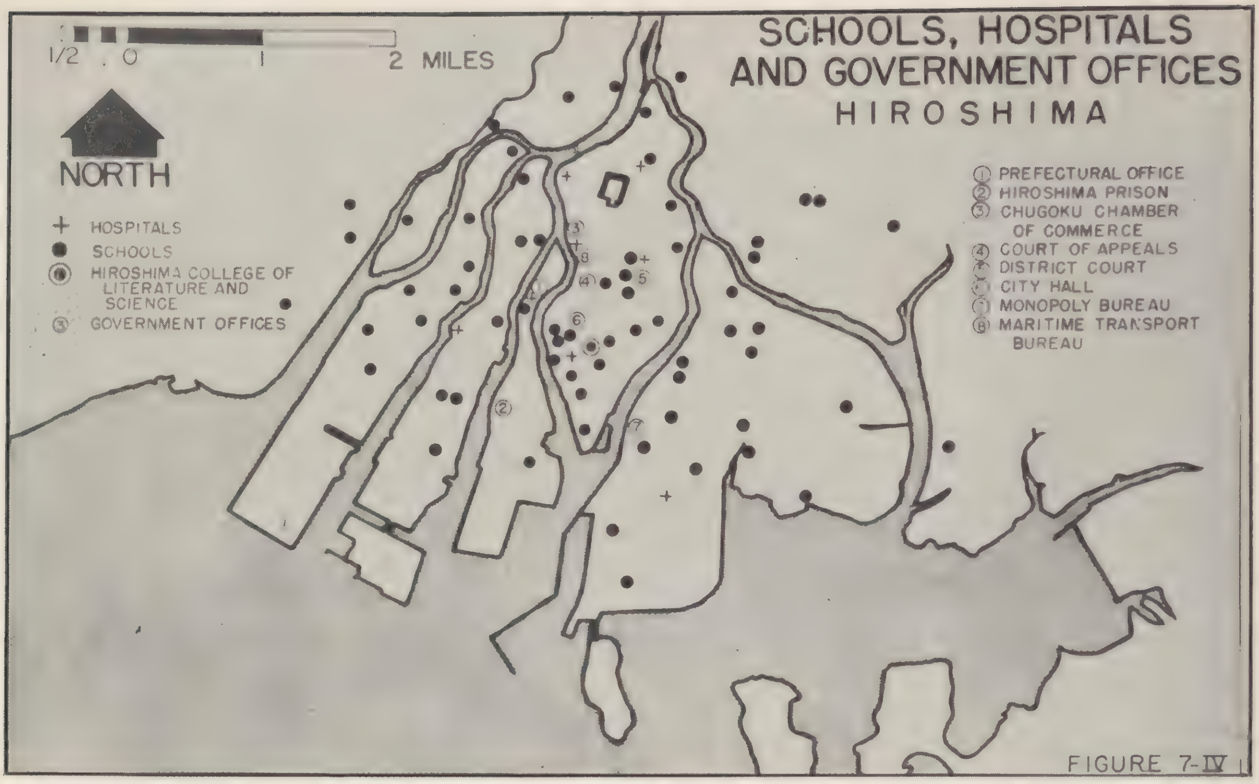


FIGURE 7-IV

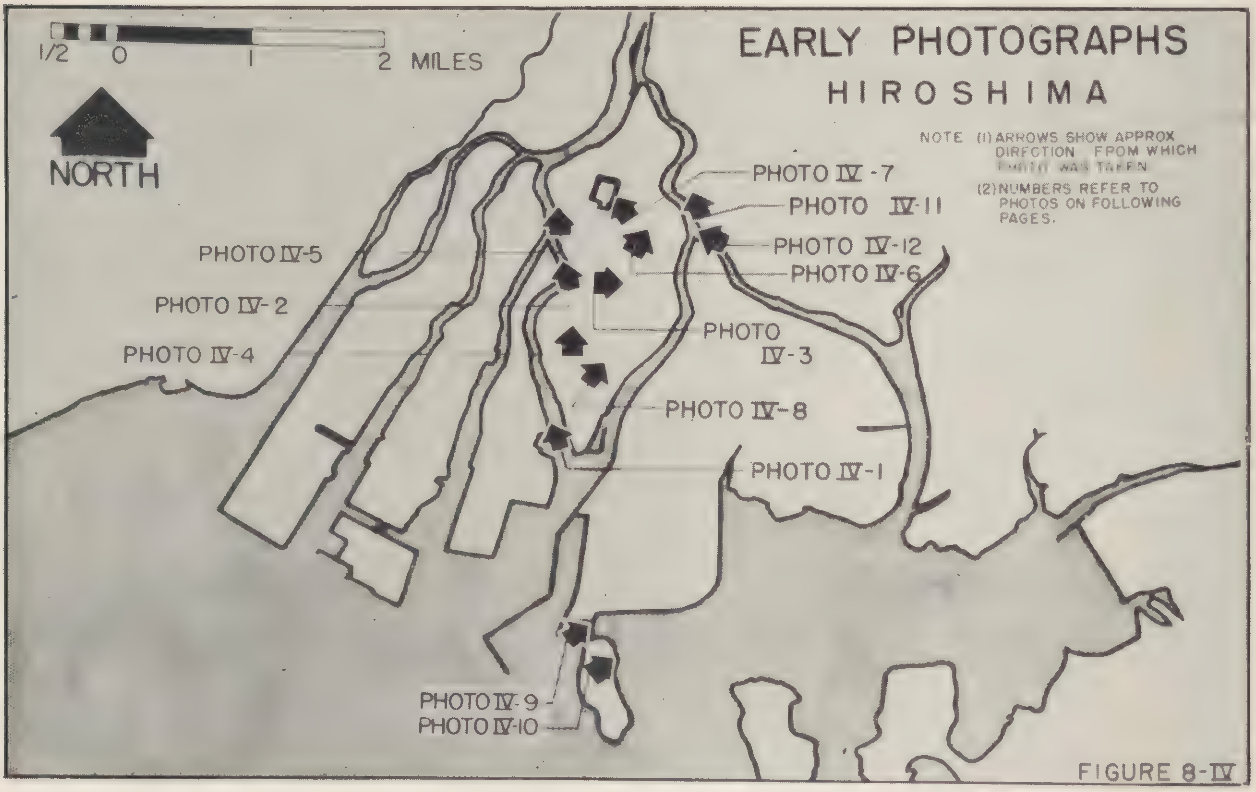


FIGURE 8-IV

PHOTO 1–IV. Aerial view of the densely built-up area along the Motoyasu-gawa looking upstream. Except for very heavy masonry structures, the entire area was devastated. Ground zero of the atomic bomb was upper right in the photo, opposite the second bend in the river.

PHOTO 2–IV. Early photograph looking upstream on Motoyasu-gawa at Bridge 22 and City Commercial Display Building (domed building) which were immediately adjacent to ground zero.

PHOTO 3–IV. Photograph of the downtown shopping district near the center of town. Only rubble and a few utility poles remained after the explosion and the resultant fires. This street was equivalent to the very famous Tokyo Ginza. Photo was taken facing east.

PHOTO 4–IV. Looking north-northeast along Tera-machi, the Street of Temples. This road is considerably wider than most roads found in residential areas. This district was completely ruined.

PHOTO 5–IV. Old photo looking north from vicinity of T-bridge. The picture shows extremely combustible wood houses along the bank of the Ota-gawa, and the characteristic Jap river craft.

PHOTO 6–IV. RADIO STATION JOFK. This modern building in the northern section of the city housed the studios, offices, and transmitter unit for the JOFK radio station. This was one of the few stations that operated on over 10,000 watts in the Japanese homeland. This building was typical in design of most of the modern one- and two-story commercial buildings in Hiroshima. Additional transmitting unit located approximately 5 kilometers north of the city was connected by cable.

PHOTO 7–IV. FORMER IMPERIAL HEADQUARTERS. During the Sino-Japanese War the Emperor Meiji made Hiroshima his headquarters; this building within the grounds of the old castle is part of his administrative center. Early in the recent war this area was the headquarters of the 5th Army, and later, the 2d General Army, responsible for the defense of southwest Japan.

PHOTO 8–IV. HIROSHIMA UNIVERSITY OF SCIENCE AND LITERATURE, AND HIGHER NORMAL SCHOOL. The Higher Normal School was one of two such institutions in Japan. In 1929 the Hiroshima University was first founded and combined with the Normal School. This building located 4,500 feet from ground zero was completely destroyed.

PHOTOS 9–IV and 10–IV. UJINA HARBOR. This relatively small harbor was developed as port for the city of Hiroshima, and has been one of the principal embarkation depots for the Japanese Army since the Sino-Japanese War. Only 20 percent of the harbor facilities were available for civilian activities. One of the important functions of Ujina Harbor was to act as the base for trade and communications with the Matsuyama area on the Island of Shikoku. Passenger steamers plying between Hiroshima, Osaka, Etajima and various ports on Shikoku and Kyushu stopped here. Fish is a Japanese dietary staple, and a fishing fleet based in Ujina Harbor operated on the Inland Sea. The harbor was never open to ships of foreign countries, but reports show that foreign trade amounting to about 500,000,000 yen was handled at the port by Jap ships in 1935.

PHOTO 11–IV. NIKITSU SHRINE. Nikitsu Shrine, near the foot of Futaba Mountain, is a part of Enko Park in northeastern Hiroshima. Although considered one of the most beautiful ones in the city, in general design it is more or less typical of Shinto Shrines found all over Japan. The woody hillside is a characteristic design feature.

PHOTO 12–IV. SENTEI POOL. The Sentei Pool, with its beautiful natural setting, was one of the most famous sightseeing and recreation places in Hiroshima. It was located east of the castle near the bank of the Kyobashi River. The building shown in the photo was the public tea house.

Shinto shrines, Buddhist temples, and Christian churches were all found in the city of Hiroshima. In State Shinto, adopted during the early days of the Meiji Restoration, the emperor had an effective religious weapon for obtaining the complete loyalty of his subjects. In addition to State Shinto, there are 13 formal sects of the religion with formal systems of worship, and Popular Shinto, the most basic type, which deals with more personal problems, such as the success of the rice crop and the welfare of the family. The Buddhist religion was imported from China, and has an enormous following in Japan. It is a purely mystical faith. Christianity has never been fully sanctioned by the leaders of Japan, and has not had any marked effect on Japanese civilization as it has in other countries.

SECTION V

HIGH-EXPLOSIVE ATTACKS ON HIROSHIMA

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Attack of 19 March 1945	81
Attack of 30 April 1945	81
Figure 1	Facing p. 82

1. Summary

a. The attacks of 19 March 1945 by four or five Navy planes and of 30 April 1945 by a lone B–29 constituted the only aerial action against Hiroshima City reported by the Japanese prior to the atomic-bomb attack of 6 August 1945. Of the two attacks, only the Navy strike is listed by the Office of Statistical Control, Headquarters, AAF (Table 1).

b. The 2 small bombs (presumed to be 250 pounds each) dropped in the attack of 19 March 1945, together with the 10 500-pound bombs dropped in the heart of the city in the attack of 30 April 1945, give a total weight of 5,500 pounds.

c. Since the area affected by these attacks later suffered severely from the atomic bomb it is impossible to evaluate accurately the effective damage done. The following figures are therefore offered only as a recapitulation of damage figures obtained from interrogation of residents and city officials. For bomb falls refer to figure 1.

Casualties

Attack of—	Killed	Wounded	Total
19 Mar. 1945	2	None reported	2
30 Apr. 1945	10–15	25–30	35–45

Damage to buildings

Attack of—	Destroyed	Minor damage	Total
19 Mar. 1945	2	None reported	2
30 Apr. 1945	22	2	24

Of the total buildings damaged, 22 were typical Japanese domestic structures, 3 were wood-frame, and 1 was of load-bearing, brick-wall construction.

2. Attack of 19 March 1945

Two small bombs were dropped on Hiroshima between 0730 and 0800 (local time) on 19 March by four or five carrier-based planes, presumably Grummans. Most of the information in connection with this attack was ascertained through interrogation of Mr. Shintaku, of the east fire station, and Messrs. Watanabe and Kobayashi, of the city engineering department.

a. The carrier-based planes came in from the northwest and while in the vicinity of the Hiroshima railroad station dropped one bomb in a river causing no damage, and one in a residential section causing two deaths and destroying two houses of domestic construction. In addition, the planes strafed along the railroad tracks but caused no damage. For bomb falls refer to figure 1.

3. Attack of 30 April 1945

Ten 500-pound bombs were dropped on Hiroshima during this attack. The bombs were dropped from a lone B–29 on 30 April 1945 at 0655 (local time) and fell within grid areas 5H and 6H as shown on the bomb plot map, figure 1 included in this section. The following data are a summary of information gathered through observation and interrogation of residents and substantiated on 10 November 1945 by interrogation of Y. Yamani, chief of the west side fire department, and S. Nimura, city architect-engineer. Mr. Yamani was the most valuable source of information since

TABLE 1.—*Air attacks on Hiroshima Prefecture*

A/F target	Date	1* Organ	Number of A/C	2* AB		2* HE		IB Frag
				Size	Tons	Size	Tons	
20th Urban Area	22 Apr 1945	8888	1			3	2	
Do	4 May 1945	8888	1			3	2	
Do	28 May 1945	8888	1			3	3	
Do	6 Aug. 1945	8888	1	98				
Navy Airfield	19 Mar. 1945		7			3	2	
Navy Bay (ships)	do		11			2	1	
Do	do					8	11	
Do	do		12			3	12	

*1 *Code (Organization) 8888-Daylight tactical mission.*
*2 *Code (HE size):*
2=250 300-lb. GP.
3=500 600-lb. GP.
8=1,000-lb. SAP.
98=not indicated.

he had been fire chief at the time of this high-explosive bomb attack and had on record a report of the resulting fire and the fire-fighting efforts to bring it under control. He accompanied the investigating party and pointed out the exact location of each bomb fall. Mr. Nimura contributed information which checked with Yamani, and assisted in locating the bomb falls on the bomb plot map.

a. Inasmuch as the bombs landed within the area which later received heavy damage from direct and indirect effects of the atomic bomb, most evidence was destroyed except the crater near the temple from bomb 2 and the crater in the street from bomb 5. These two craters were partly filled but the diameters indicated that they had been caused by 500-pound bombs.

(1) Bomb 1 made a direct hit on the Nomura Life Insurance Building causing serious structural damage. The building remained unrepaired and was completely burned out by fires resulting from the atomic-bomb attack.

(2) Bomb 2 landed near a temple causing minor damage.

(3) Bomb 3 made a direct hit on a warehouse behind the Chugoku Electric Co. and started fires which burned for two hours, destroying electric wire and cable, transformer oil, paint and a small amount of gasoline. This was the only fire damage caused by the attack.

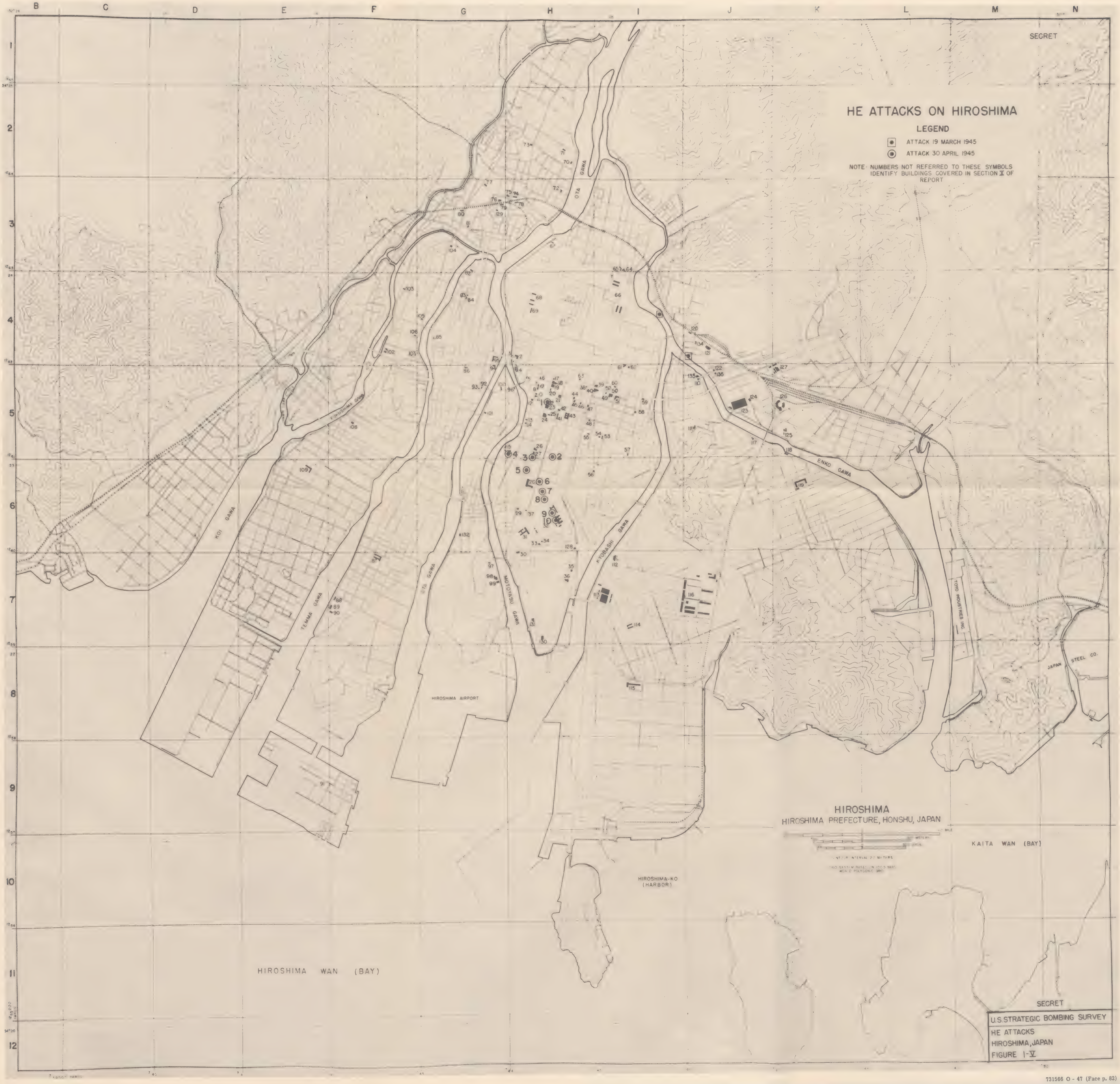
(4) Bomb 4 fell in a residential section causing structural damage to approximately 20 houses of typical Japanese construction.

(5) Bomb 5 formed a crater in an asphalt-surfaced cobblestone street.

(6) Bombs 6, 7, and 8 landed in low-density residential areas and did little or no damage.

(7) Bombs 9 and 10 fell in the Hiroshima University grounds, bomb 9 landing in an open area and bomb 10 causing minor damage to a building approximately 75 feet distant.

b. Casualties from all ten bombs were estimated at 10 to 15 killed and 25 to 30 wounded.


SECRET
HE ATTACKS ON HIROSHIMA
LEGEND
ATTACK 19 MARCH 1945
ATTACK 30 APRIL 1945
NOTE: NUMBERS NOT REFERRED TO THESE SYMBOLS IDENTIFY BUILDINGS COVERED IN SECTION X OF REPORT
OTA GAWA
ENKO GAWA
KYOBASHI GAWA
MOTOYASU GAWA
TEMMA GAWA
KOI GAWA
HIROSHIMA AIRPORT
TOYO INDUSTRIES INC.
JAPAN STEEL CO.
HIROSHIMA
HIROSHIMA PREFECTURE, HONSHU, JAPAN
KAITA WAN (BAY)
HIROSHIMA-KO (HARBOR)
HIROSHIMA WAN (BAY)
SECRET
U.S. STRATEGIC BOMBING SURVEY
HE ATTACKS
HIROSHIMA, JAPAN
FIGURE I-V

SECTION VI

THE ATOMIC-BOMB ATTACK

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1. Source of Information

a. No details of the attack preparations, approach to the target, dropping of the bomb, elements of the explosive, or method of detonation of the bomb dropped on Hiroshima are available for this report. It is, therefore, necessary to describe the attack as experienced and reported by the Japanese themselves. The information contained in this section was obtained through interrogation, and from Japanese atomic-bomb reports prepared by the Kure Naval District and the governor of Hiroshima Prefecture. The originals and translations of these reports are on file with the Intelligence Section of the United States Strategic Bombing Survey.

2. General

a. Although Hiroshima Bay and surrounding airfields had received several attacks, the city itself had experienced no large-scale bombing attacks prior to the atomic-bomb attack on 6 August 1945. Residents stated, however, that it was not an uncommon sight to see formations of American planes pass over the city on their way toward other targets. Two small-scale, high-explosive attacks had been made on the city: one with four or five carrier-based planes on 19 March 1945, and the other by a single B–29 on 30 April 1945 (Sec. V).

b. Defense plans for the evacuation of personnel and construction of firebreaks were drawn up in the fall of 1944 when the Japanese people began to realize that their island empire was no longer beyond the reach of American land-based bombers. At the time of the atomic-bomb attack the city had entered what was termed the sixth evacuation period, although just what stage of completion this involved is not known.

3. Conditions on Morning of Attack

a. The morning of 6 August 1945 was clear with a small amount of clouds at high altitude. Wind was from the south with a velocity of about 4½ miles per hour. Visibility was 10 to 15 miles.

b. An air-raid "alert" was sounded throughout Hiroshima Prefecture at 0709 hours. Reports of the number of planes causing this alert were conflicting. The governor of the prefecture stated that four B–29s were sighted, while the Kure Naval District reported three large planes.

c. The aircraft apparently came out over Hiroshima from the direction of Bungo Suido and Kunisaki Peninsula, circled the city, and withdrew in the direction of Harima-Nada at 0725 hours. "All-clear" was sounded at 0731 hours.

d. The following circumstances account in part for the high number of casualties resulting from the atomic bomb:

(1) Only a few persons remained in the air-raid shelters after the "all-clear" sounded.

(2) No "alert" was sounded to announce the approach of the planes involved in the atomic-bomb attack.

(3) The explosion occurred during the morning rush hours when people had just arrived at work or were hurrying to their places of business. This concentrated the population in the center of the city where the principal business district was located.

(4) Many persons residing outside the city were present for reasons of business, travel and pleasure.

(5) National volunteer and school units were mobilized and engaged in evacuation operations.

4. Time, Altitude and Direction of Attack (Diagram 1)

a. Although some confusion exists as to the exact time of the explosion, it is safe to state that it took place within a minute before or after 0817 hours.

b. Although no air-raid "alert" sounded, the planes committed in the attack were sighted as early as 0806 hours when Matsunago lookout station reported two enemy planes proceeding northwest. This was corrected to three planes at 0809 hours.

(1) The sound of aircraft engines from the direction of Saijo was picked up by Nakano searchlight battery at 0814 hours.

(2) Enemy aircraft were reported over Saijo proceeding west at 0815 hours. (Nakano searchlight battery reported sighting two aircraft flying 700 to 1,000 feet apart at 23,000 feet, heading southwest. Diagram 2.)

c. Planes arrived over Hiroshima at an altitude of 28,000 feet. There were varying reports on the number of planes, but it was generally agreed that three aircraft were sighted—one plane was in the lead, and two followed abreast separated by a distance of 700 to 1,000 feet. The lead plane was seen to change course to the right while the two following planes were observed at 0817 hours to release parachutes and turn to the left. Nakano searchlight battery reported the release of an object attached to a parachute which failed to open. At this moment the bomb detonated.

d. Following the detonation, the lead plane was seen heading east or northeast. Nothing further was reported concerning the activities of the other two planes, although one light aircraft was sighted heading south at a low altitude.

e. It was not definitely established which plane dropped the bomb, but it was presumed by the Japanese that the lead plane carried the bomb since the two following aircraft released parachutes.

5. Japanese Description of Explosion

a. Survivors of the atomic-bomb attack stated that the detonation seemed like a vast combustion of magnesium filling the entire sky. These persons reported that the flame contained various colors such as greenish-white and yellowish-red. Reports of the duration of the flash varied from instantaneous to 2 to 4 seconds. At the same time an overpowering heat wave emanated from the source of the flash.

b. The entire city of Hiroshima was darkened by a dense pall of smoke and dust, which limited visibility to a few feet. From a distance, a mushroom-shaped cloud was seen expanding and covering the entire city. It then rose, reaching a height of 23,000 feet 4 minutes after the explosion. The column began to disintegrate after 8 minutes, the top of the mushroom separating itself from the column and remaining intact. The color of the column was gray and white while the ball on top was white tinged with crimson.

c. In the center of the city a violent blast of air immediately followed the flash, knocking down trees and poles, stripping branches off trees, tearing sheets of galvanized metal off buildings, derailing streetcars, and squashing or knocking over houses.

d. A slight interval between the flash and the blast was noted by persons who were removed from the center of the city.

e. Few persons in the downtown area heard any noise of explosion. They were aware only of a blinding flash and the overpowering heat and wind. Outside the city, however, a loud rumbling noise was heard.

f. Fires soon broke out throughout the city and developed into an engulfing inferno in the central area of destruction. Some of the fires were caused by direct ignition of thatched roofs, curtains, trees, and the like but the majority resulted from secondary effects.

g. Directly after the explosion survivors reported finding in some places a "substance" which emitted a weak, bluish-white fluorescent light. This substance, upon contact, burned through or ignited combustible objects. When it fell upon clothing it burned through to the flesh, producing water blisters which gradually diffused and became extremely painful.

h. Following the explosion, strong, changeable winds arose, attaining velocities of 25 to 35 miles per hour. Whirlwinds were reported at a few points.

i. While the fires were spreading, there was a light rainfall throughout the central part of the city, with occasional heavy showers in the northwestern section.

6. Eyewitness Accounts of Explosion

a. A Kure Navy Yard war worker who was 2½ miles west of Hiroshima at the time of the explosion stated, "I saw a single enemy airplane flying over Hiroshima. It released (or fired) a brilliant object. I thought at first that it was an incendiary bomb, but then I saw someting that looked like a smoke ring from a funnel gradually falling toward the ground. It grew larger almost immediately and increased in brilliance and soon covered an area almost equal to that of the city of Hiroshima. A flame appeared which was even brighter than the sun. I thought I might get hurt so I fell flat on the ground."

b. Two Kure Navy Yard war workers who were located 6 miles northwest of Hiroshima when the bomb exploded said:

> We felt a blast of hot air accompanied by a bright light. Looking at the sky immediately afterward we noticed an enemy plane in the center of a dark-colored column, surrounded by the blue of the sky. The column undulated. At two places in the column we noticed white smoke which gradually expanded. We fell to the ground and heard a loud explosion. White smoke could be seen rising in the direction of Hiroshima.

c. A technician from Kure Navy Yard who was at Hiroshima Railroad Station, Advance Terminal, said:

> I noticed what appeared to be an enemy B–29 turning to the right at a high altitude as it proceeded north directly overhead. Immediately afterward I saw what seemed like an incendiary bomb exploding to the rear of the plane (in the sky to the south). It was followed by a flash (1 to 2 seconds in duration). Thinking it was an incendiary bomb, I started to take shelter in the station building but had gone only a few steps when I felt a tremendous concussion strike me from behind. I immediately fell to the ground and covered my face.

7. Inactivity of Defense and Fire-Fighting Organizations

a. Fire-fighting and defense units were helpless against the explosion and resultant fires. About 70 percent of the fire-fighting equipment was destroyed but the remainder was usable. An appeal for help was made immediately to fire companies outside Hiroshima, but it was not until approximately 1100 hours that this help was able to get through to the outskirts of the city. No attempt was made to fight fires in the center of the city and all equipment was engaged in attempting to control fires on the outskirts.

b. Air defense, civilian defense, and neighborhood volunteer units completely disintegrated. Escape from the surrounding confusion and agony was the thought foremost in the minds of the survivors. A few individuals did engage in immediate first-aid work, but it was not until afternoon that it was possible to mobilize personnel in sufficient numbers to administer first aid extensively.

8. Estimate of Bomb and Explosion

a. The Japanese estimate of the center of the detonation was determined by the same method that the survey team followed. Ground zero was ascertained by careful study of the flash-burns and blast marks on trees and houses throughout the city, from which the direction of blast was calculated. Air zero was computed by taking the angles of elevation of shadows formed on scorched surfaces by opaque obstacles in the paths of the radiated rays. The Japanese calculated the center of the explosion to be at an elevation of approximately 1,800 feet over a point 980 feet south of the Gokoku Shrine, between Aioi Bridge and Kamiya-cho. (The survey calculated AZ to be 2,000 feet.)

b. The only conclusion immediately reached about the bomb itself was that it was an extremely powerful explosive of an heretofore unused type. It was only after the announcement by American radio stations that an atomic bomb had been dropped on Hiroshima that the Japanese became aware of the atomic characteristics of the missile.

9. Ultra-Short-Wave Transmitters

a. The ultra-short-wave transmitting units dropped by parachutes at approximately the time the atomic bomb was released were objects of intensive study by the Japanese (diagrams 3 and 4). The exact relationship between the transmitting units and the bomb itself was not discovered.

b. Three of these transmitting sets were found in unbroken condition in the mountains 12½ miles north of Hiroshima. The following is a description of the sets quoted from the Kure Naval District report:

> The objects consisted of a light-metal cylinder attached to a parachute at one end so that the cylinder could be suspended vertically; the lower extremity of the cylinder consisted of a transparent plastic hemisphere containing a clockwork control mechanism. The cylinder was found to contain powerful electric cells and an ultra-short-wave transmitting unit. An air-pressure diaphragm was secured on the outside and was connected with the electrical apparatus and the clockwork mechanism contained in the hemisphere and cylinder, thereby constituting a powerful transmitting unit which would change the transmitting frequency in accordance with external air pressure variations. The electrical system of this apparatus was connected to an antenna which extended from an opening in the extremity of the cylinder, and was attached to the top of the parachute in such a manner as to extend upward toward the top of the parachute * * *. No explosive elements were contained in this equipment.

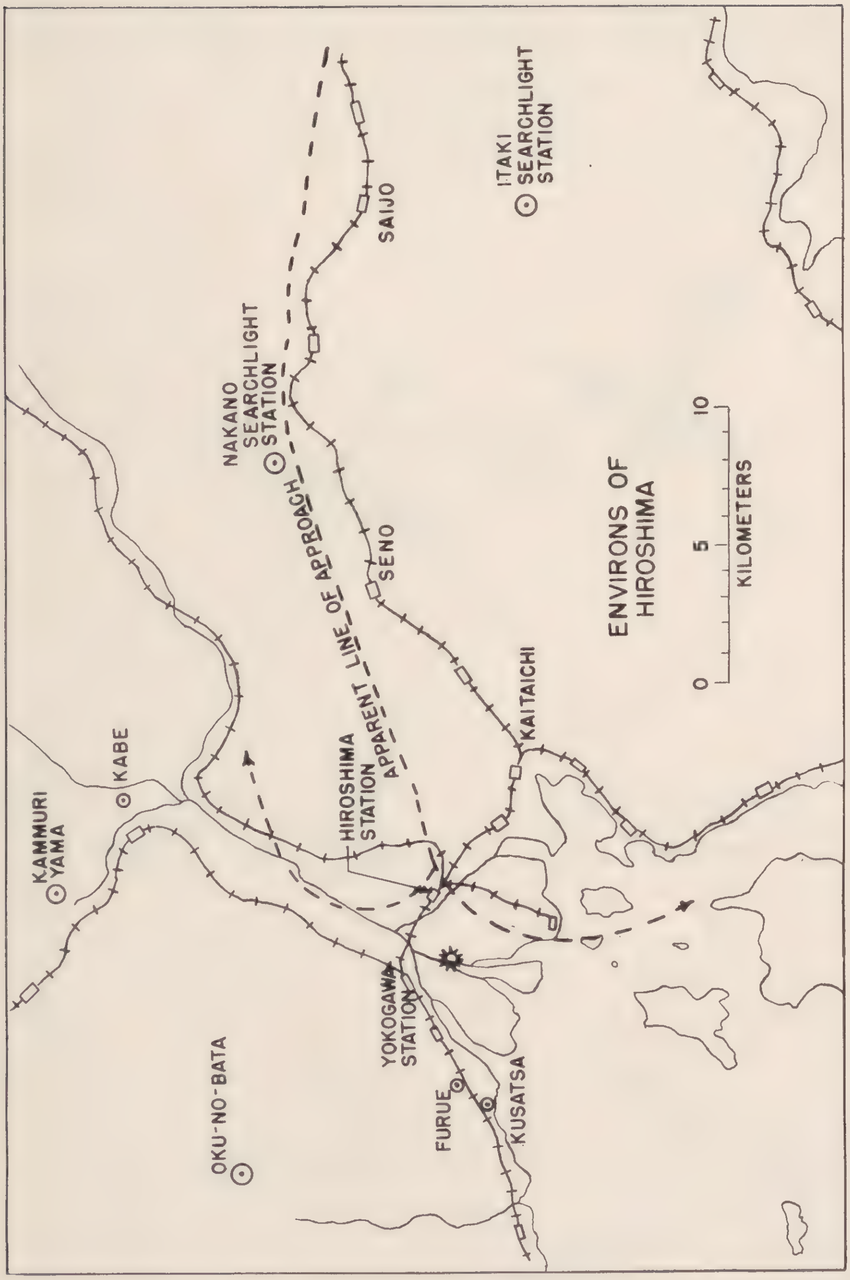

ENVIRONS OF HIROSHIMA
KAMMURI YAMA
KABE
HIROSHIMA STATION
APPARENT LINE OF APPROACH
NAKANO SEARCHLIGHT STATION
SENO
SAIJO
ITAKI SEARCHLIGHT STATION
KAITAICHI
YOKOGAWA STATION
OKU-NO-BATA
FURUE
KUSATSA
0
5
10
KILOMETERS

DIAGRAM 1

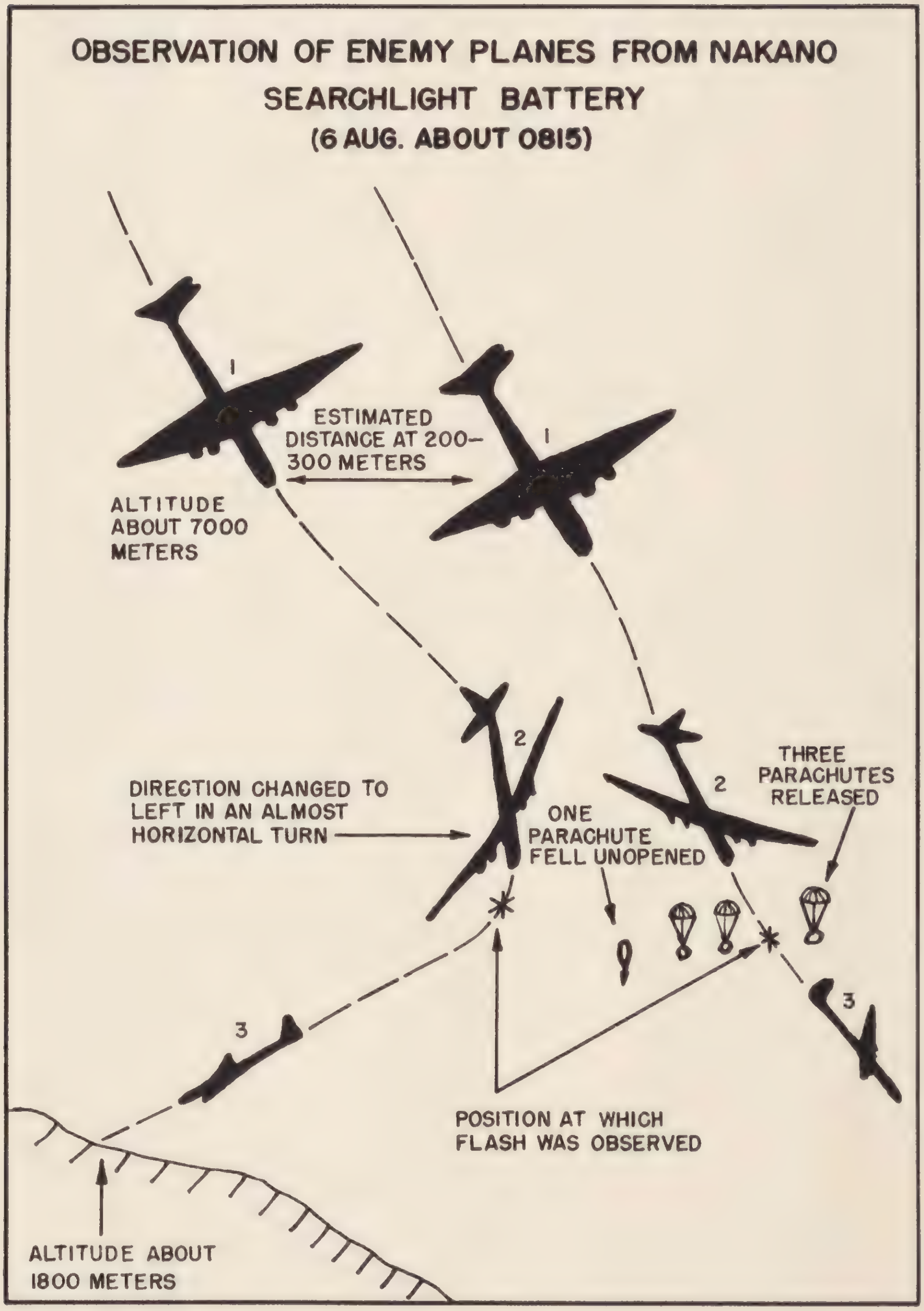

OBSERVATION OF ENEMY PLANES FROM NAKANO
SEARCHLIGHT BATTERY
(6 AUG. ABOUT 0815)
1
1
ESTIMATED
DISTANCE AT 200-
300 METERS
ALTITUDE
ABOUT 7000
METERS
2
2
DIRECTION CHANGED TO
LEFT IN AN ALMOST
HORIZONTAL TURN
ONE
PARACHUTE
FELL UNOPENED
THREE
PARACHUTES
RELEASED
3
3
POSITION AT WHICH
FLASH WAS OBSERVED
ALTITUDE ABOUT
1800 METERS

DIAGRAM 2

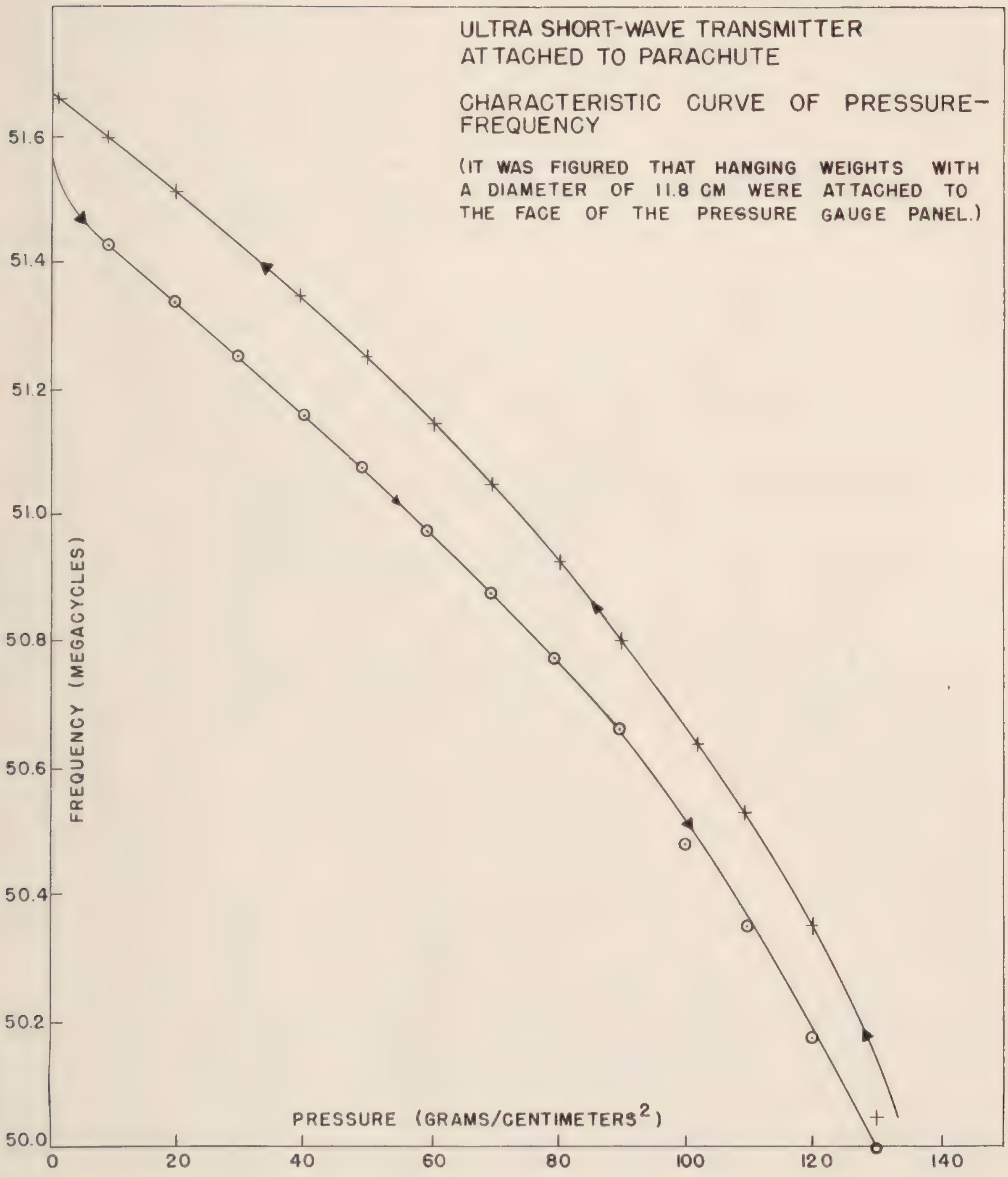

ULTRA SHORT-WAVE TRANSMITTER
ATTACHED TO PARACHUTE
CHARACTERISTIC CURVE OF PRESSURE-FREQUENCY
(IT WAS FIGURED THAT HANGING WEIGHTS WITH A DIAMETER OF 11.8 CM WERE ATTACHED TO THE FACE OF THE PRESSURE GAUGE PANEL.)
FREQUENCY (MEGACYCLES)
PRESSURE (GRAMS/CENTIMETERS²)
51.6
51.4
51.2
51.0
50.8
50.6
50.4
50.2
50.0
0
20
40
60
80
100
120
140

DIAGRAM 3

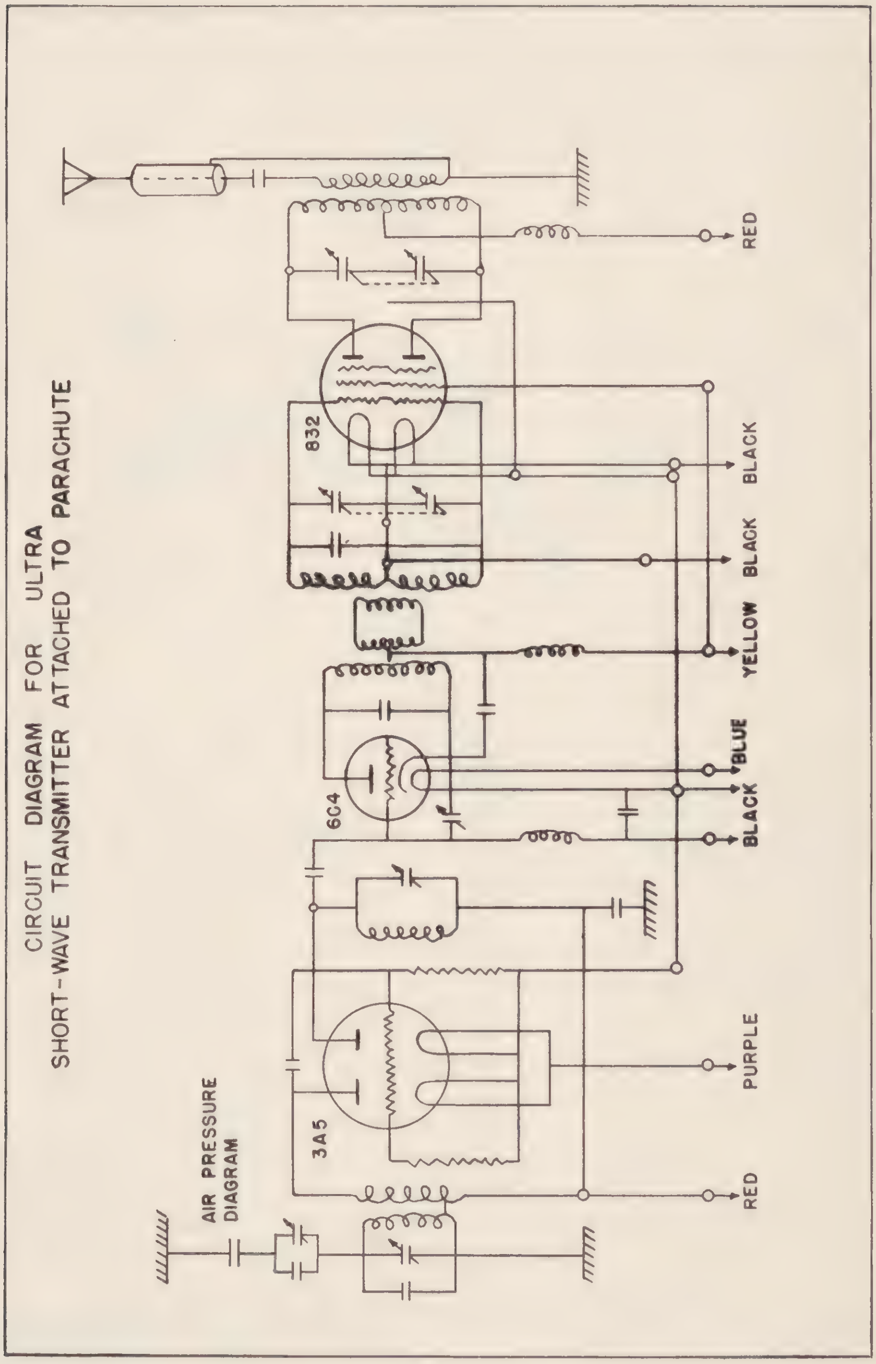

CIRCUIT DIAGRAM FOR ULTRA
SHORT-WAVE TRANSMITTER ATTACHED TO PARACHUTE
AIR PRESSURE
DIAGRAM
3A5
6C4
832
RED
PURPLE
BLACK
BLUE
YELLOW
BLACK
BLACK
RED

DIAGRAM 4

SECTION VII

DETERMINATION OF AIR ZERO

	Page
Summary	92
Definition	92
Location and elevation	92
Method	92
Accuracy	92

Photos 1 to 4, inclusive.
Figure 1.

1. Summary

The point of burst of the atomic bomb is referred to as "zero," a point determined to be in grid 5H approximately 700 feet southeast of the T-bridge, at an elevation of slightly over 2,000 feet. The location of zero in both plan and elevation was developed from flash marks found on surfaces readily scorched or spalled by radiation of heat from the explosion. Marks or unscorched areas which were delineated by "shadows" on surfaces that were shielded by some object in the path of the radiation or heat wave afforded directions and elevations for the location of the point of detonation.

2. Definition

The zero point may be defined as the point of detonation of the atomic bomb. The point had location in both plan and elevation, inasmuch as the bomb burst in the air. Throughout this report the ground location of the point immediately under the burst is designated as ground zero, abbreviated to GZ, and the actual point of detonation in the air is designated as air zero, abbreviated to AZ.

3. Location and Elevation

GZ was found to be in grid 5H at coordinates 744,200–1,261,850 (fig. 1). Air zero, determined from an average of seven computations, was found to be slightly over 2,000 feet.

4. Method

Both AZ and GZ were determined from flash marks found on buildings, bridges, and other structures or objects. The flash marks resulted from the scorching of surfaces such as wood, asphalt, paint, or the spalling of granite from radiation of the intense heat of explosion. Objects obstructing the path of the heat wave cast their "shadows" which were actually unscorched areas. The edges of the "shadows" upon horizontal surfaces led to the location of GZ, and upon vertical surfaces permitted the computation of AZ. Photos 1 to 4, inclusive, show typical flash marks.

a. Ground zero was located by extending to an intersection the lines formed by various flash marks on horizontal surfaces. The lines were extended by sighting by eye across objects placed at two points along the mark and alining stakes ahead to a point of intersection with other lines similarly extended. Six such lines were run from flash marks found on the granite door sill of building 6, 600 feet east of GZ; on granite objects in the shrine, approximately 800 feet north of GZ; on the granite shrine, 900 feet northeast of GZ; on the asphalt roadway, 250 feet west of GZ; on the ornamental granite work on building 11, 800 feet southeast of GZ; and on bridge 22, 250 feet southwest of GZ. Other marks were used to check the point obtained by intersection of the lines listed above.

b. Air zero was determined from marks made on vertical surfaces, usually outlined by overhanging objects or members which "shadowed" portions of the surfaces. The legs of the triangle formed *a* and *b* in figure 1, were measured with a scale or steel tape, and the horziontal distance (base line) to GZ was scaled from the map. The base line was checked, where practicable, by actual measurement on the ground. Thus, similar triangles were formed which permitted simple calculation of the height of burst, or AZ. Seven such computations were made with base lines ranging from 600 to 6,600 feet. The marks actually used in determining AZ were on a granite lantern post at entrance to shrine, 600 feet north of GZ; asphalt surface of bridge 20, 2,900 feet southwest of GZ; wooden window frame of penthouse on Electric Building 26, 2,300 feet south of GZ; tile wall surface of Electro-Technical Laboratory Building 74, 6,000 feet north of GZ; asphalt surface of bridge 30, 1,900 feet southwest of GZ; asphalt roof of Communications Building 85, 3,300 feet northwest of GZ; and Gas Holder, 6,600 feet south of GZ.

5. Accuracy

The degree of accuracy attained in locating GZ and AZ was limited by circumstance, but it is believed to be adequate for the purpose of evaluating effects of the bomb. All measurements were made from flash marks, which, although easy to see, were not sharply defined along the edges. This lack of sharp delineation was probably caused by the fact that the source was not actually a point but an oblate sphere of fire in which the major axis was vertical. Elevation measurements therefore, could not be made with precision and minor inaccuracies were inevitable.

a. *Ground Zero*. All points of intersection of the lines extended from the six flash marks fell well within a circle of 50-foot radius. Although the method used in the determination may appear inaccurate, it must be pointed out that more

precise methods (such as use of a transit and tape traverse) would have attained no greater degree of accuracy inasmuch as the edges of the flash marks were not sharp lines. The selection of the edge of the "shadow" was a matter of judgment which could nullify the precision of extending a line by means of a transit. Surveys made by the Japanese (Chugoku Electric Co., and the city architect) placed GZ in the same general area as that determined by this team.

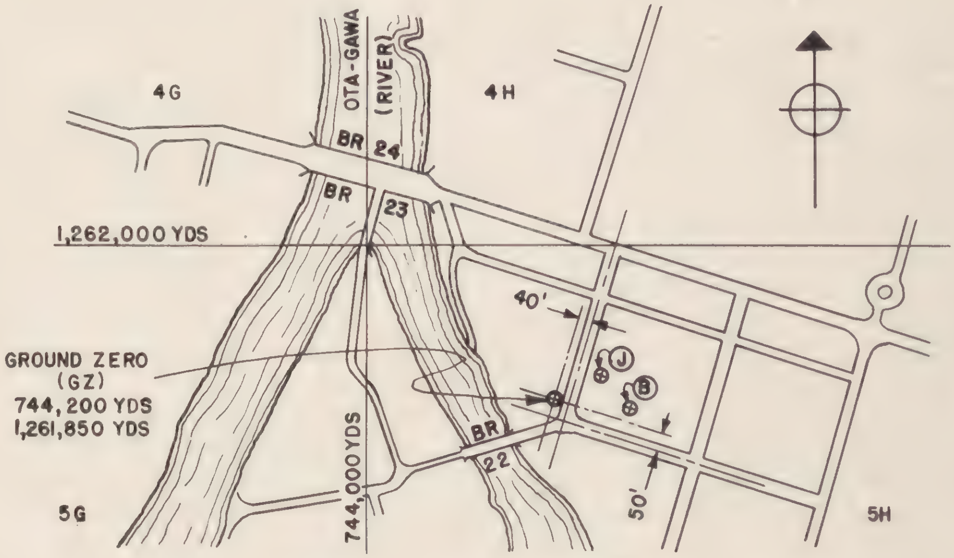
b. Air Zero. The seven calculations of AZ ranged from 1,600 feet to 2,300 feet and averaged slightly over 2,000 feet. This figure is believed to be correct within 200 feet. Japanese surveys made independently by the Chugoku Electric Co. and the city architect established AZ's of 500 meters (1,635 feet) and 800 meters (2,620 feet), respectively. A survey was also made by the Kure Naval District, and the following is taken from their report of September 1945, paragraph 5, page 17:

> The carbonization of timbers in the vicinity of Ushida and the Hiroshima University of Literature and Science caused by the radiated blast showed comparatively clear shadows which were formed by obstacles in the path of the radiated rays. From this, the angle and direction of the source of the rays were clearly determinable. Taking the horizontal distances and angles from these points, the altitude of the center of the blast was calculated and figures of 580 meters and 510 meters, respectively, were obtained. From this, the altitude of the burst was figured to be approximately 550 meters * * *.

The average of the four findings of the Japanese was 1,970 feet. The height of AZ as determined by the British is taken from the preliminary report of the British Mission to Japan, paragraph 2.1.2, page 10, which reads as follows:

> Enough measurements, however, were taken in each place to confirm the general location of GZ as that marked as the center of the circles on the accompanying maps; and to give reasonable estimates of the height of burst. These are:
>
> Hiroshima—Just below 2,000 feet.
>
> Nagasaki—Approximately 1,750 feet.
>
> These are the distances between GZ and AZ. Since GZ was effectively at sea level at both places, they may be taken as heights of bursts above sea level.

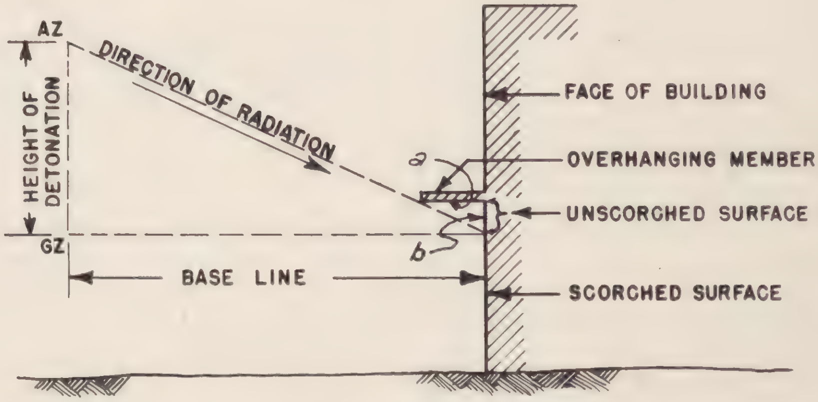
The calculations of the British and Japanese surveys placed AZ slightly under 2,000 feet, which closely approximates the result obtained by calculations of this team.



LOCATION OF GROUND ZERO (GZ) AS DETERMINED FROM FLASH MARKS.

Ⓙ - LOCATION OF JAPANESE DETERMINED GZ

Ⓑ - LOCATION OF BRITISH DETERMINED GZ



TYPICAL CASE OF FLASH MARK USED IN COMPUTATION OF AIR ZERO (AZ).

SECRET

U.S. STRATEGIC BOMBING SURVEY

DETERMINATION OF ZERO POINTS
HIROSHIMA, JAPAN
FIGURE I-VII

PHOTO 1–VII. Showing flash marks on asphalt deck of bridge.

PHOTO 2–VII. Showing flash marks on granite lantern post.

PHOTO 3–VII. Showing flash marks on celotex-type wallboard.

PHOTO 4–VII Showing flash marks on granite steps.

SECTION VIII

TYPICAL JAPANESE DWELLINGS

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1. Object of Study

Although the Japanese had to a great extent adopted Western construction practices for their industrial, civic and large commercial buildings, their dwellings remained of a design and construction indigenous to Japan and, therefore, unfamiliar to most Americans. Since residences comprised the bulk of any urban area, a complete understanding of this type of building was necessary before the damage to an urban target, such as Hiroshima, could be fully comprehended. It is the object of this section to present the data pertaining to the typical dwelling, which affected its vulnerability to fire and blast weapons, and their effects thereon.

2. Residential Areas

Residential areas in Hiroshima, like those in other Japanese cities, were characterized by a high degree of built-upness resulting from a density of population comparable to some of the worst slum districts in large American cities (photos 1–3). Various sizes of one- and two-story, wood-frame buildings roofed with tile were built close together along the streets, with numerous outhouses, wood garden walls and fences to the rear of the houses occupying most of the remaining ground area within a block. Streets were very narrow and laid out in a rectilinear pattern except where topographical features interfered. Sidewalks were not common, the streets being used for pedestrian as well as vehicular traffic. Open gutters carried drainage and waste water from houses on each side. In areas where the residential section was not clearly defined, small combination shop-dwellings were found, with the shop opening directly onto the street and the owners living to the rear or in the second story. These buildings, however, did not differ from the usual dwellings in details of construction.

3. The Dwelling

a. Background. The Japanese dwelling was developed into its present form to satisfy the need for a suitable structure in which to carry out the highly traditional family and social life. The characteristics of the house which are usually criticized by the Occidental (flimsiness of construction and stark simplicity of interior) can be explained by the fact that the Japanese found in these qualities an answer to his own particular needs. His home was not designed to furnish the maximum of comfort, but to serve primarily as a shelter. Permanency of construction was not considered a particularly desirable feature. This concept of a dwelling was strengthened by, and probably resulted from, his experience with earthquakes, fires, and typhoons which have ravaged his country since the beginning of time. Thus, if disaster struck, he could rebuild his home at relatively low cost from local materials. Superstition, which was so closely interwoven with Japanese tradition, also exerted an influence on the planning of his dwelling in the form of "Kimon", the science of conciliating the household gods. Few Japanese would build a house before presenting its plan to one of the scholars of his "science" to determine whether or not the various parts of the house were auspiciously situated in relation to the center, or if misfortune were liable to befall the occupants. Favorable dates for starting construction and moving in were also determined in this manner.

b. Dwellings in Japan varied from the one-room hut of the poor to the multi-room mansions of the wealthy, therefore no one residence that could be designated as typical in all respects. Except for a few Western style houses, however, most Japanese residences were of the same type construction and utilized the same materials. The description below, therefore, can be applied to nearly all Japanese dwellings.

c. Description. In general, the dwelling was a one- or two-story, unpainted, wood-frame structure with a heavy tile, wide-eaved roof of graceful lines. Exterior walls were straw-reinforced-mud plaster on a lath mat of split bamboo. The mud was usually finished with a thin coat of fine sand, clay, or white lime plaster. Thin boards were sometimes placed over the plaster along the lower parts of the wall for protection (photos 5–6). On one side, large areas of glazing in sliding sashes made it possible for the house to be opened up on the garden. Sliding sashes with panels of translucent, white rice paper were also used for most interior doors and partitions. Fixed interior partitions were similar to exterior walls. Floors were covered by closely fitting straw mats (Tatami) except in passageways, baths, toilets, and kitchens. These mats were of a standard size, 6 feet by 3 feet, and 2 inches thick. Room sizes were referred to by the number of mats a room contained. A suspended ceiling of thin wood sheets was used throughout the house. Neither attics nor basements were found in Japanese dwellings. Figures

PHOTO 1–VIII. Roof-line view of Japanese residences crowded about a small cove on the outskirts of Hiroshima. Note the typical tile roofs, the nearly uniform height of the houses and the high degree of built-upness.

PHOTOS 2–VIII and 3–VIII. The high degree of built-upness that is a characteristic of Japanese cities and villages is shown in these aerial views of typical residential districts. The lower photo shows a fishing village. Its expansion has been restricted by high hills and overcrowding has resulted.

4–6, inclusive, are drawings of one- and two-story dwellings.

4. Rooms and Furnishings

a. Plan. The simplest Japanese dwelling consisted of an entrance, a living room which also served as a dining room and bedroom, minimum toilet facilities, and a kitchen which might or might not be within the main structure. In larger homes the plan was expanded to include additional rooms similar to the living room, a bath, and, in some cases, one room furnished in Occidental style (Western room). When these additional living rooms were available they ceased to be used as multi-purpose rooms and acquired definite functions such as guest, dining or sleeping rooms. The room actually used as a living room probably would be the only one which would include a "Tokonoma" (recess for ornaments); otherwise the rooms would be similar in design and furnishings and could be used interchangeably. The different types of rooms usually found in a Japanese dwelling are described in paragraphs *b–h* below, and their relation to each other can be seen in the plans in figures 4 and 6.

b. Entrance (photo 7). The Japanese residence was entered through sliding doors of wood inset with panes of either clear or translucent glass. These doors, which were at grade level, admitted one to the Genkan, a small room similar to a vestibule, which provided the transition between the street and the interior of the house. The finished floor of the house, which was approximately 18 inches above grade, extended part way into the Genkan, necessitating an additional step between the house floor and the stone or concrete floor of the entrance. It was at this step that shoes were removed before proceeding into the house. A cabinet or a series of shelves were provided for the shoes. There was no other furniture in the Genkan. Another set of wood sliding doors with rice paper panels separated the entrance from a hallway which gave access to other rooms of the house. In addition to this entrance the more expensive dwellings had a smaller one for family use only. When two Genkans were present the larger one was more elaborate and some kind of formal decoration was generally used. Screens or partitions were so placed within the house that the areas used for domestic purposes could not be seen from the garden.

c. Living Room. This room (photos 10–14), the largest and most frequently used in the residence, was the center of activity, answering the purposes of living, dining, and bed rooms. It always occupied the most favorable location in the house, usually along the side where it could overlook the garden and be exposed to the winter sun and the summer breeze. At least one and more often two of its walls were sliding wood sashes with panels of rice paper which could be opened or removed entirely, allowing the room to merge with those adjacent to it or to open up on the garden. Straw mats (Tatami) laid on a thin wood subfloor, gave a soft, resilient quality to the floor, and accentuated the rectilinear patterns which occurred in all walls and openings. A very light ceiling of thin wood was suspended over the room. It was in the living room that the traditional, ornamental recess (Tokonoma) was found, usually extending the entire width of the room. These recessed areas conformed to certain established proportions and methods of construction, but the arrangement of the cupboards (Jibukuro) and shelves (Tana) might vary somewhat. Closets for clothing and bedding were located in the living room or in an adjacent passage.

d. Living Room Furnishings. The following is a list of the articles of furnishings and ornaments most often found in a living room.

(1) Dia—A low table used for dining, etc.
(2) Zabutona—Small cushion seats.
(3) Hibachi—Charcoal brazier.
(4) Kakemono—A decorative scroll, hung in the tokonoma.
(5) Jibukuro—Storage cupboards within the tokonoma.
(6) Tana—Small shelves for ornaments, also within the tokonoma.
(7) A small dressing chest with mirrow and drawers.
(8) Various ornaments, such as dolls and carvings.
(9) Bedding—At night the bedding was removed from its closet and spread on the floor, thereby converting the living room into sleeping quarters.
(10) Other items, such as large cabinets and sewing machines, were occasionally found in larger homes, but they were not standard furnishings.

e. The Kitchen (photo 15). The kitchen of the Japanese house was a small room, located so that it would have direct access to the outside, but never in a conspicuous place in relation to the

garden or living room. In some cases it was detached from the house. The floor was of wood or dirt, and usually one step below the level of the other rooms in the house. A small, masonry range heated by charcoal was used for cooking unless gas was available and within the means of the family. This range was crude, consisting of a simple firebox into which charcoal was placed and ignited through an opening near the bottom. As a rule much fanning was necessary before sufficient heat was generated to warm the utensil which rested on a grate over a circular opening in the top of the stove. A sink and drain board were built into one wall. Other furnishings included a work table, cabinets and shelves for the numerous trays, bowls, and dishes.

f. Toilet (*photo 17*). The Japanese depended upon night-soil for fertilizer to such an extent that few flush-type water closets were used. The toilet (Benjo) was a simple fixture fitted in an opening in the floor. Beneath the floor was a pit lined with wood or concrete which caught the excrement which was collected periodically and carted to farms for use as fertilizer. The small compartment which the toilet occupied had a tile or wood floor, plaster walls with tile or wood wainscoting, and sliding doors, sometimes opening directly onto a passageway. Except in the smaller homes, a lavatory was located in an adjoining compartment or in a small recess off the passageway. The bath was seldom placed in close proximity to the toilet and lavatory as is customary in the United States.

g. Bath (*photo 16*). The room in which the Japanese bathed was usually a small, concrete-floored room with a wooden tub built into one corner. Beneath the tub, which was about 2½ feet deep, a charcoal stove was installed to heat the water. This stove was usually fired from outside the room. Wood slats were usually placed over the concrete floor which drained to an open gutter outside the house. Walls were of plaster with wood wainscot, although tile for floor, wainscot and exterior of the tub was frequently used in more expensive homes. Clothes were removed in an adjoining compartment or on a raised section of the floor and placed on shelves along the wall. The text for Photo 16 describes briefly the procedures followed by the Japanese when bathing. As all Japanese could not afford to have bath rooms in their homes, public baths were maintained in cities and towns.

h. Western Rooms. Japanese in the higher-income brackets usually furnished one room of their residence in what they referred to as the Western style. The typical straw mats were replaced by a hardwood-finish floor; permanent partitions were constructed; swinging doors were used in place of sliding wall panels; and the room was furnished with Western style furniture. A false fireplace often completed the "Westernization" of the room.

5. Photographic Description

a. The photos on the following pages illustrate the principal features of the Japanese dwelling. Most of the photos are of a residence considerably larger and more expensive than could be afforded by the average Japanese family. As indicated in paragraph 3*b*, however, the same materials and construction features were found in all Japanese dwellings, regardless of cost or size. In this respect, therefore, the photos shown can be considered typical.

6. Materials

a. Wood. An abundance of timber in Japan and the natural preference of the inhabitants for this medium combined to make wood by far the most common material used in the construction of dwellings. Temperate zone conifers, which are considered the best construction material, were found throughout most of Japan and used extensively. Bamboo was sometimes used for structural members in addition to its more common uses as drains, laths, siding, and decoration As cut lumber was expensive, rough timber was utilized to a great extent, being shaped on the job by the carpenter. Japan did not have the wide variety of dimension lumber found in the United States.

b. Plaster. This material, which was used for exterior panel walls and fixed partitions in most Japanese dwellings, was manufactured on the site by reinforcing clay or mud with rice straw. It was applied on lathing or strips of split bamboo tied with straw. A fine sand or white lime plaster was usually used as a finish.

c. Tile. Heavy, vitreous tile was used almost exclusively for roofs of residences in urban areas. Glazed tile for wainscoting and floors was found in some baths, toilets and kitchens.

d. Glass and Paper. Nonstructural glass and thin, translucent rice paper provided the panes in windows and doors. Some interior sliding sashes were covered with a heavy, opaque rice paper.

e. Other Materials. Concrete, brick, and stone were used to some extent for floors in baths and

PHOTO 4–VIII. Exterior and forecourt of a large Japanese residence. Note the elaborate tile roof. The wooden shutters seen on the right are locked in place across all entrances at night.

PHOTO 5–VIII. Another view of the above house, showing large corner window with sliding sash. The circular window has obscure glass in fixed sash. Opening in fence to left leads to garden.

PHOTO 6–VIII. Photo taken at rear of same residence. The panel walls are mud plaster on bamboo lath with a white lime plaster finish. The bamboo wainscot protects the plaster. Note the numerous roofs and the half-timber construction.

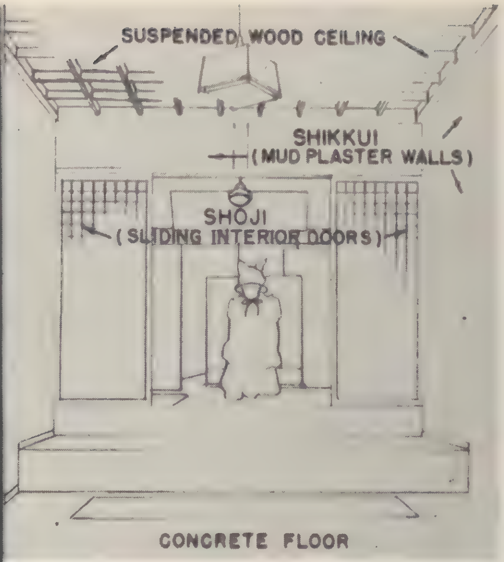


PHOTO 7–VIII. ENTRANCE. The entrance (Genkan) of a large Japanese residence. The photo was taken just inside the exterior doors.

PHOTOS 8–VIII and 9–VIII. INTERIOR PASSAGE. Interior view of passage along garden side of house from the entrance. The sliding sash on both sides of the passage allows the rooms to be opened to the garden. The relation of the rooms to the garden can be seen in the photo below.

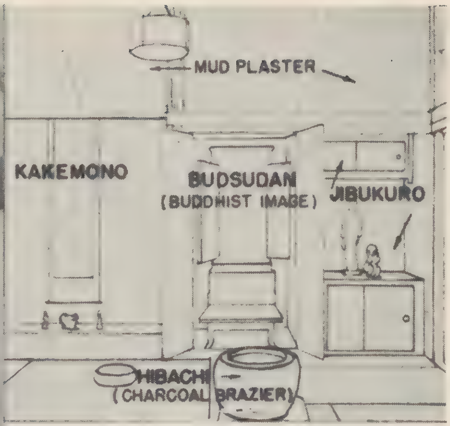
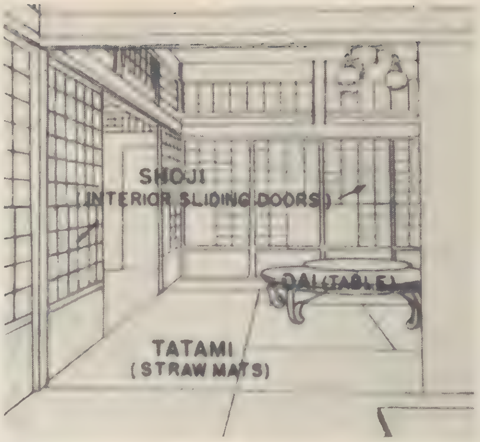


PHOTO 10–VIII. Living room showing a Buddhist image incorporated into the design of a tokonoma.

LIVING ROOM: Note that in the above photo the inclusion of the budsudan has not altered the basic proportions of the tokonoma, which are standarized. The cabinet containing the budsudan is called a butsuma. The Japanese warm their hands over the charcoal brazier, or hibachi, which is the only source of heat in most dwellings. Photo 11 shows one variation in the arrangement of the jibukuro, the cupboards in which small articles for the living room are stored. The table with the revolving top is of heavy wood with a lacquer finish, and of a somewhat better quality than is found in average homes. The dolls in the tokonoma are popular forms of decoration in Japan.

PHOTO 11–VIII. Interior view showing the furnishings of a Japanese living room.



PHOTOS 12–VIII and 13–VIII. Photographs and sketches of interior and furnishings of a living room. Construction and materials are typical but the quality is above average.

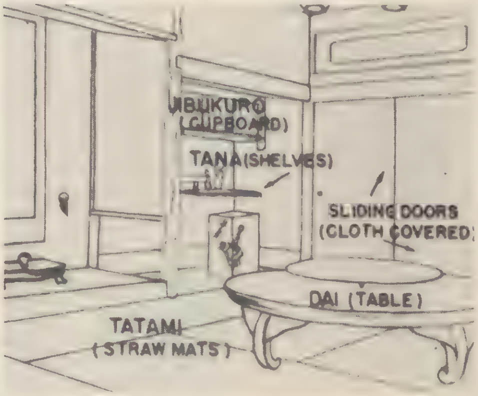


PHOTO 14–VIII. THE BED. This photo of a Japanese bed shows the ease with which a living room can be converted into sleeping quarters. The bed consists of two heavy blankets similar to our comforters. When not in use they are stored in the closets on the right. A low mirrored dressing table (not shown here) completes the bedroom furnishings. The unshaded light bulb is typical.

PHOTO 15–VIII. KITCHEN. This kitchen was described as modern by the owner. Located to the left of the sink was a typical masonry firebox with two grated openings in the top. In such stoves charcoal is placed, ignited, and fanned to provide heat for cooking. Cabinet space in the kitchen provided storage for utensils.

PHOTO 16–VIII. BATH. The ritual of the bath in Japan consists of lathering, washing, and rinsing before entering the tub of very hot water to soak and relax. Floors, tubs, and wainscots of wood are more common than tile. Slatted wood floors drain the water from the sponge bath. A charcoal stove, fired from the outside, heats the water.

PHOTO. 17–VIII. TOILET. Flush-type water closets are seldom found in Japanese residences. The Benjo shown in the photo is a porcelain fixture through which the excrement falls into a pit where it is collected and carted away to farms for use as fertilizer. Large homes usually have a lavatory built in a small recess off the hallway near the Benjo. In more modest residences the Benjo is often located near the kitchen and the sink used for washing in lieu of a lavatory.

PHOTO 18–VIII. A view of one of the more elaborate gardens. It is so located that it can be seen from all the principal rooms of the house. The entire wall of the house pictured is of sliding sash which can be removed, extending the living area into the garden.

GARDENS: Gardening in Japan has become a highly developed art. So exacting is this art that every garden (elaborate as seen in Photo 18 or just a tiny spot of ground) falls into one of the many classes under the two general types: Tsukama (artificial hills) and Hira-niaw (level gardens). Each is laid out according to established formulae. Religious or philosophical significance is attached to the location or shapes of the trees, rocks, miniature hills, etc., which make up the design. There is seldom a profusion of color but rather an atmosphere of restraint, for the Japanese strive to create in their gardens a refinement so hidden beneath an ordinary outward appearance that only those with the most cultivated taste can recognize and appreciate it.

PHOTO 19–VIII. The close relationship between the living room and the garden areas is shown in this view of a modest home.

kitchens, but were seldom used as structural material in the frame of the house.

7. Construction

a. General. Residential construction in Japan was primarily the work of local carpenters. These men were, as a rule, highly skilled especially in the use of wood, and their high quality of workmanship was displayed in the delicate interiors and cabinet work of the dwelling. The practices followed, however, placed their residential construction far below American standards of strength, rigidity, and weather tightness. Apparently, sizes of members were determined by general practice and the materials available rather than by calculation of loads and stresses, and members used under the same conditions might vary greatly in size. A minimum of rough hardware was used, the members being joined by intricate joints which were cut on the job. These joints tended to cause the over-all size of members to be larger than those which would be used in American construction of a similar type.

b. Foundations. Most dwellings were supported about 12 to 18 inches above the ground by short, wood posts resting on individual footings of stone or concrete. In better construction, beams beneath exterior walls and major partitions were found in addition to individual foundations. As a precaution against earthquake, the structure of the dwelling usually was not rigidly anchored to the foundation, thus reducing to some extent the vulnerability of the structure to the effects of ground shock.

c. Frame (figs. 4 and 5). The frame of the dwelling consisted primarily of a heavy roof system, supported by 4- by 4-inch wood columns spaced about 6 feet apart around the exterior and along all major partitions. The exterior columns were framed into a heavy plate (usually about 9 by 9 inches). Heavy rough timber beams spanned the structure and supported the simple framing system of rough poles on which the purlins rested. Joints were usually mortise and tenon. No diagonal sheathing or bracing was used in the framing.

d. Floors. Interior floors not covered by straw mats were usually a single thickness of ½-inch wood flooring. This flooring was nailed to joists (approximately 2 by 1⅝ inches) spaced 1 foot 2 inches on centers. Joists were rough poles of about 4-inch diameter. Beams were spaced approximately 3 feet on centers, and supported every 3 to 6 feet along their length by individual footings. Where straw mats were used, the wood flooring was dropped 2 inches and became a subfloor for the mats.

e. Walls. Two-inch plaster panels between framing members formed most exterior walls of dwellings in Hiroshima. The plaster (par. 4*b*) was applied to a lath of split bamboo (½-to 1-inch diameter) which was lashed together with twine or straw. No insulation or inside sheathing was used. However, on some exterior walls a layer of thin boards or bamboo up to about 3 feet above ground served as protection for the plaster. Few walls of concrete, brick or stone were found.

f. Partitions. Stationary partitions were identical to exterior walls except that the protective layer of boards was not found. Movable partitions were sliding sash covered with cloth or rice paper.

g. Roof and Ceiling. Nearly all Japanese dwellings had hipped or gabled clay tile roofs of about 30° pitch. As a rule the tile was set in mud on ⅜ to ½-inch sheathing, but in some cases it was wired in place. Open ends of the tile and cracks were sealed with mud to insure watertightness. The sheathing was nailed to 2-by 1½-inch rafters which were supported by rough pole purlins (3-to 4-inch diameter). Wood straps nailed to the purlins supported a series of small strips (1 by 1 inch) across which the ⅛-inch ceiling boards were laid.

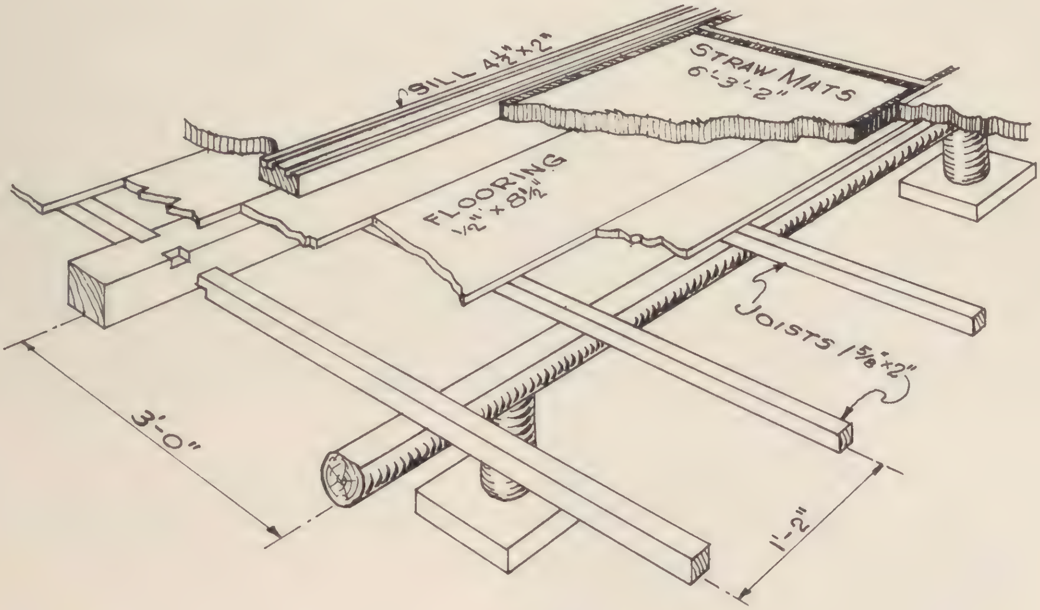
8. Blast Vulnerability

Experimental data on peak pressures or the blast impulses necessary to cause damage of varying degrees to Japanese residential construction are not available. Because of the differences in structural methods, comparison of the vulnerability to blast of occidental and Japanese residential construction is not possible except from actual experiments. Consequently, a quantitative evaluation of the vulnerability of Japanese construction to blast cannot be made. Rather generalized conclusions, however, can be drawn:

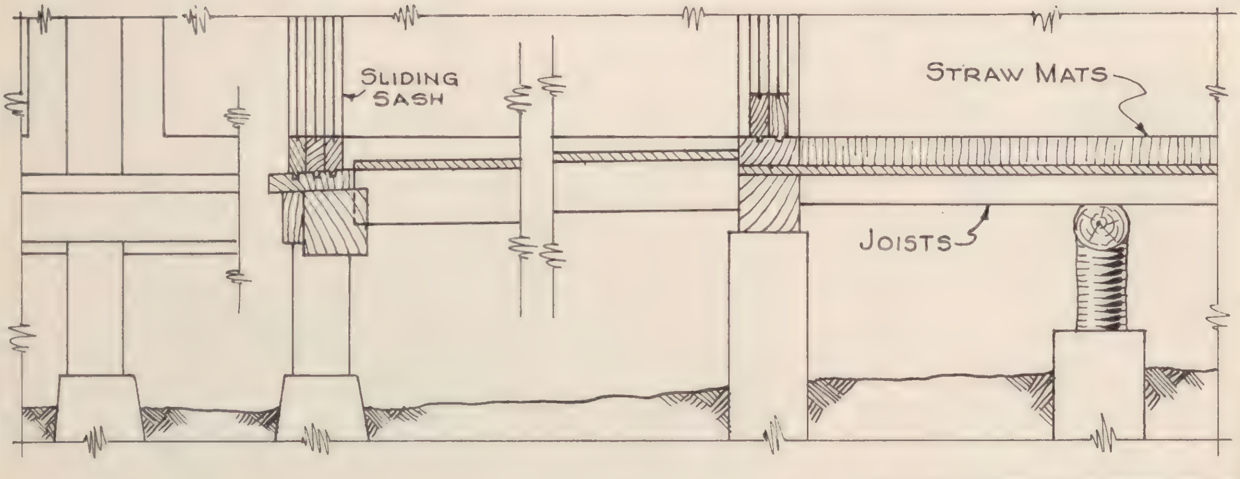
a. Resistance to blast is roughly inversely proportional to mass and strength. The typical Japanese residence (photos 20 and 22) was generally a light-frame structure consisting of a relatively heavy roof system supported by slender columns. Lateral rigidity was normally provided by moments developed by mortise and tenon joints between columns and roof beams. The

PHOTOS 20–VIII and 21–VIII. These photos show exterior views of damaged dwellings which show the typical framing of this type of building. Note the simple roof system, the lack of diagonal and lateral bracing, and the extensive use of unsawed lumber.

PHOTO 22–VIII. This shows the interior framing details of the same type of building described above.



PERSPECTIVE SKETCH



SECTION SHOWING TYPICAL
FLOOR AND FOUNDATION POSTS

U.S. STRATEGIC BOMBING SURVEY

JAPANESE RESIDENCE
FLOOR SECTIONS
FIGURE I-VIII

PHOTO 23–VIII. Damage to this typical wall panel has broken away the plaster and exposed the bamboo lath.

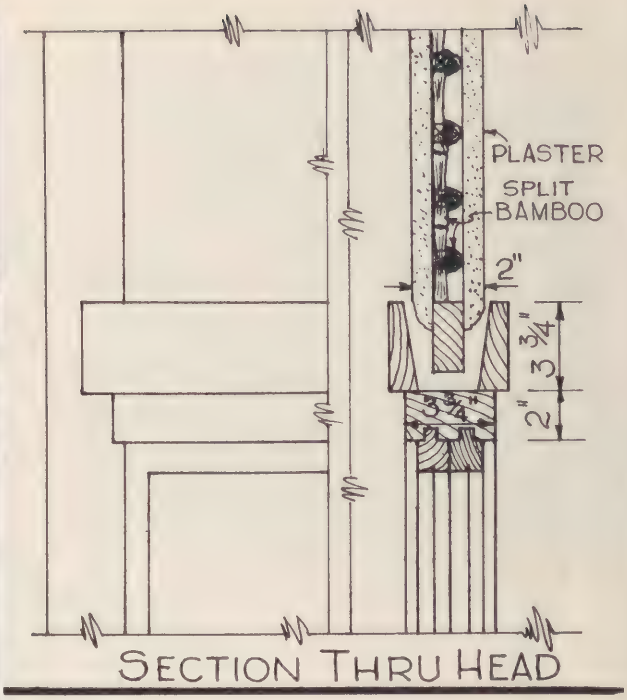


FIGURE 2–VIII. Japanese residence—Walls and partitions.

PHOTO 24–VIII. This photo of a residence under construction shows workers mixing mud plaster for the walls. The straw beside them was used as the binder for the mud. Note straw beside them was used as the binder for the mud. Note the split bamboo lath between the columns.


PHOTOS 25–VIII and 26–VIII. These photos are interior views of a dwelling in which can be seen typical roof and ceiling construction. The drawing below further illustrates this type of construction.

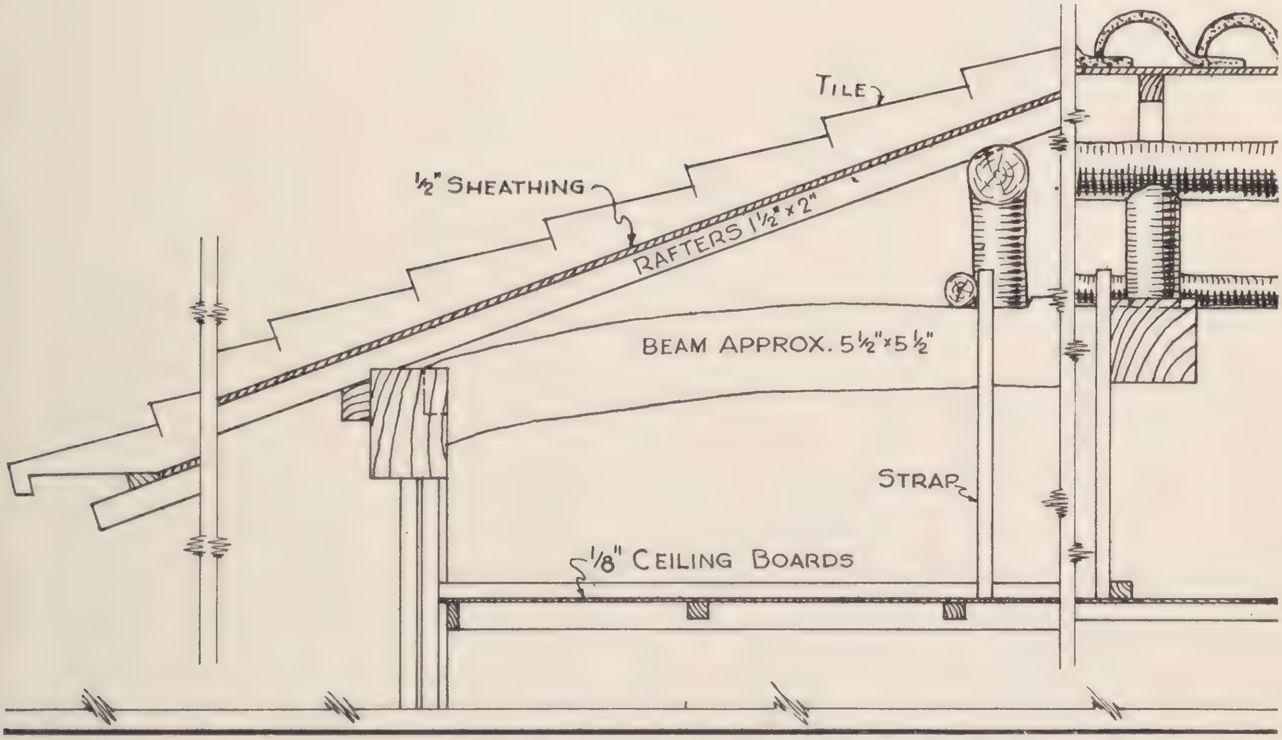
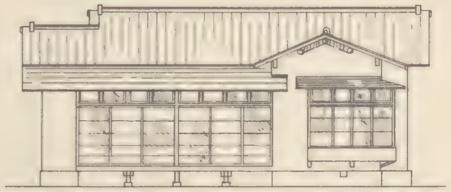


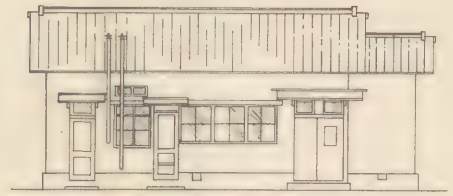
FIGURE 3–VIII. Japanese residence—Section through roof and ceiling.

SECRET

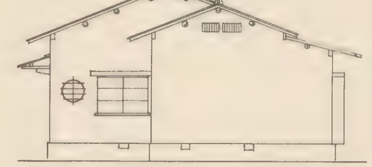


SOUTH ELEVATION

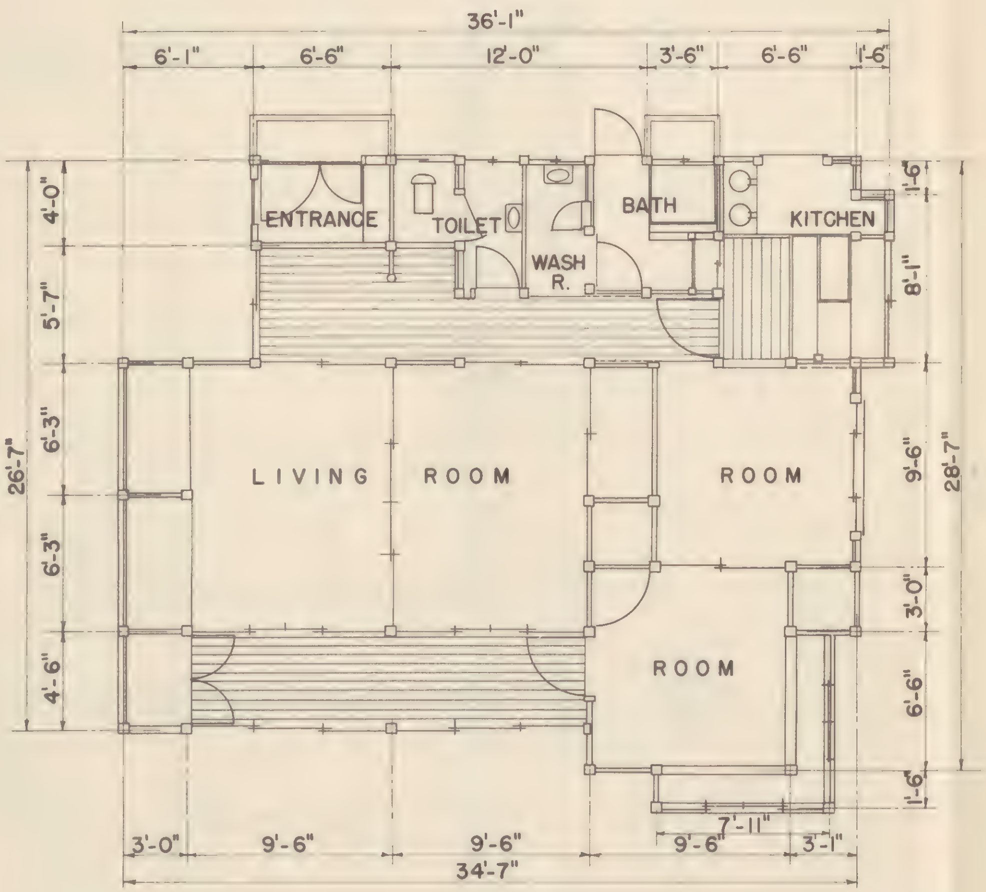
EAST ELEVATION



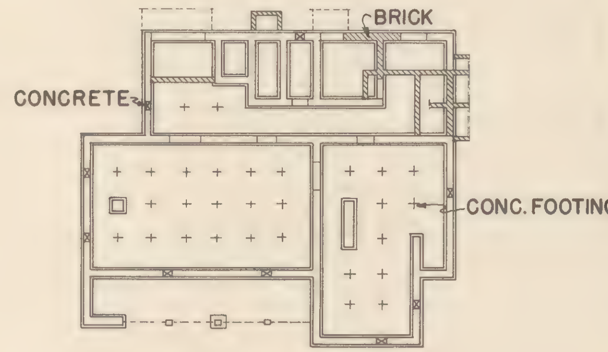
NORTH ELEVATION



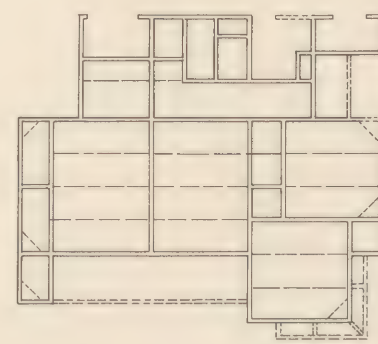
WEST ELEVATION



·PLAN·



FOUNDATION PLAN



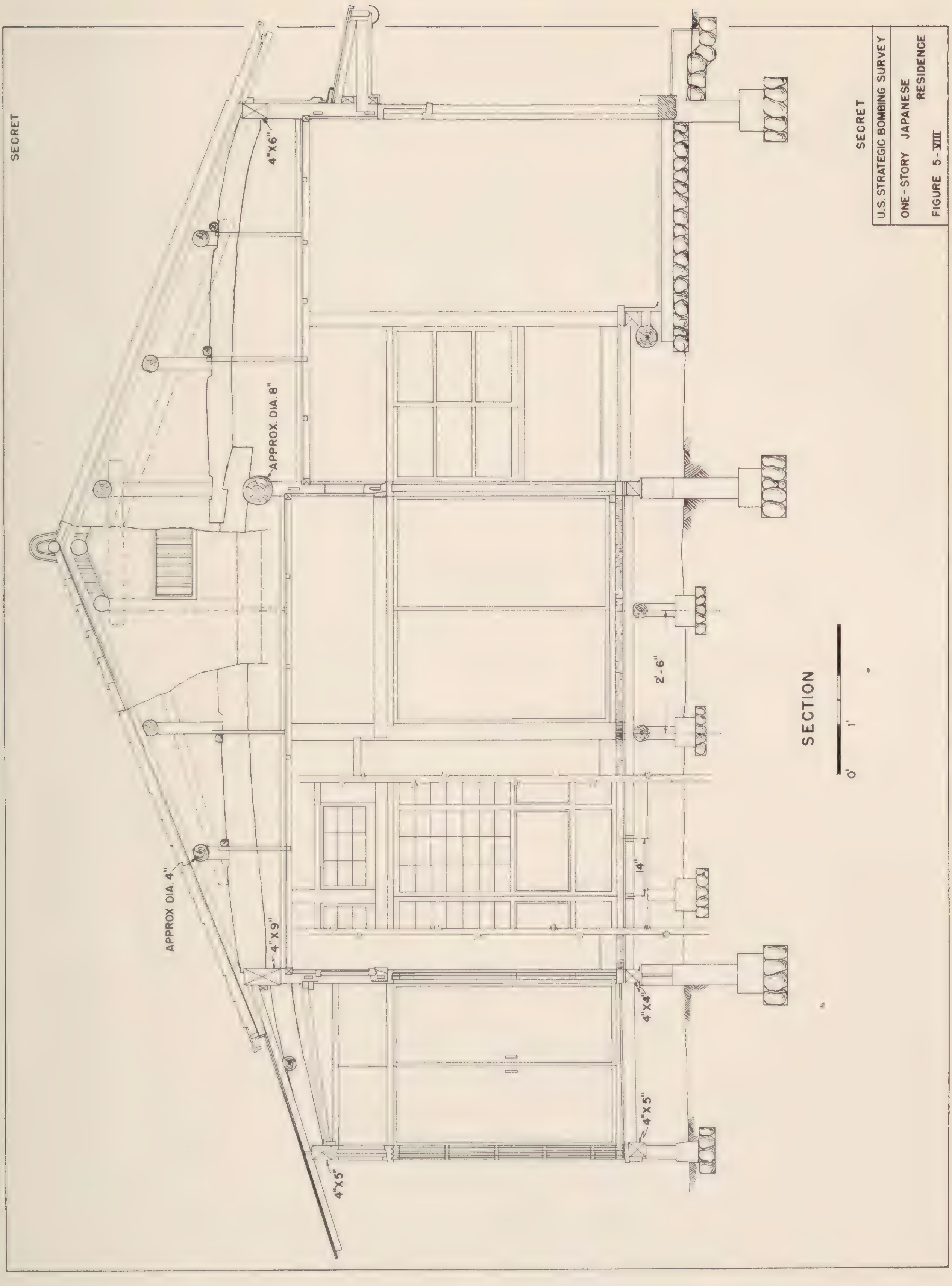
FLOORING PLAN

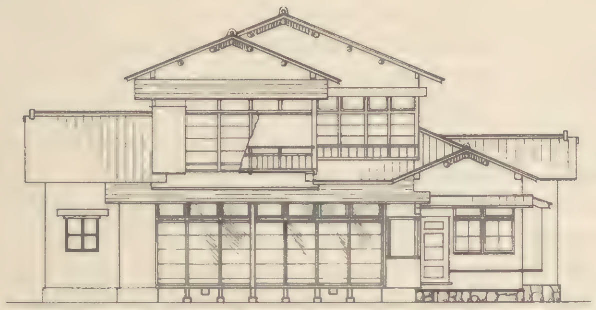
SECRET

U.S. STRATEGIC BOMBING SURVEY

ONE-STORY JAPANESE RESIDENCE

FIGURE 4-VIII

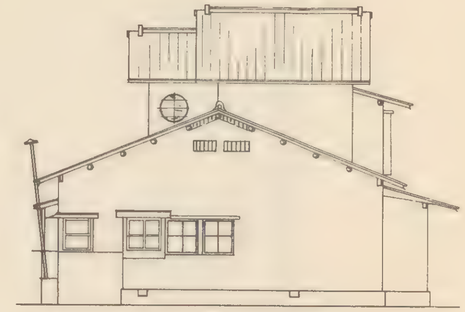

SECRET
APPROX. DIA. 8"
APPROX. DIA. 4"
4"X6"
4"X9"
4"X4"
4"X5"
4"X5"
2'-6"
14"
SECTION
0'
1'
SECRET
U.S. STRATEGIC BOMBING SURVEY
ONE-STORY JAPANESE RESIDENCE
FIGURE 5-VIII



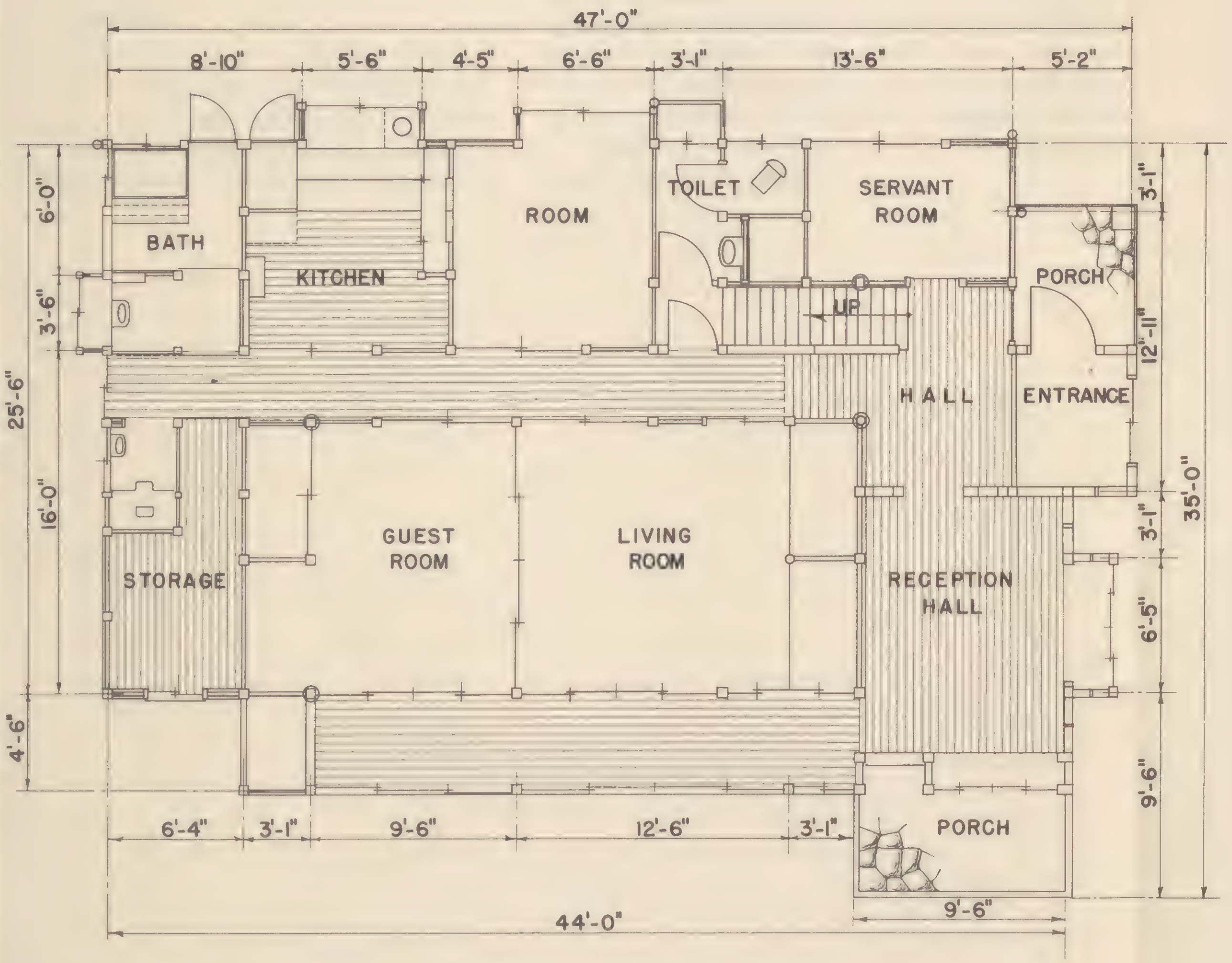
SOUTH ELEVATION

EAST ELEVATION

NORTH ELEVATION

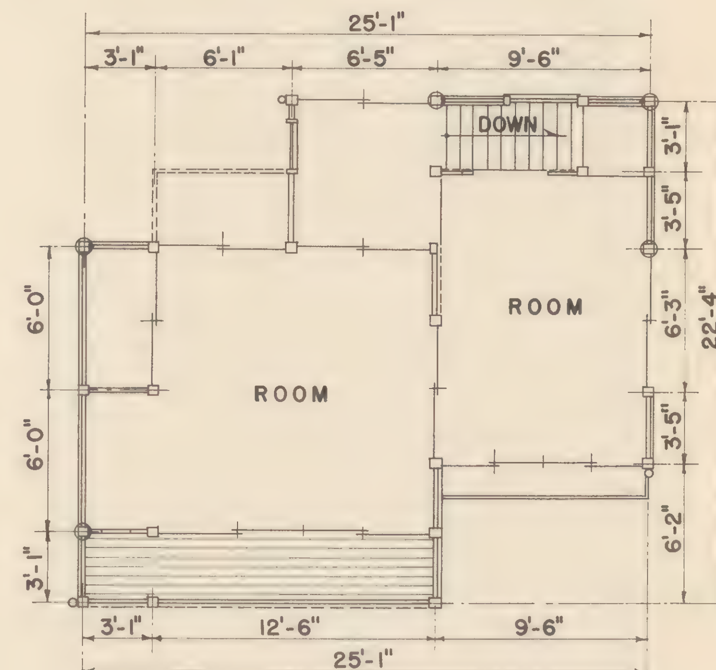


WEST ELEVATION



· FIRST · FLOOR · PLAN ·

0' 5'



· SECOND · FLOOR · PLAN ·

SECRET

U.S. STRATEGIC BOMBING SURVEY

TWO-STORY JAPANESE RESIDENCE

FIGURE 6-VIII

731566 O - 47 (Face p. 114)

panel walls of mud plaster on bamboo lath were only lightly fastened to the framing and were frequently stripped without rupturing the frame.

b. The light weight, slender columns, and weak mortise and tenon joints were points of weakness which rendered the Japanese residence highly vulnerable to damage by blast. Failures commonly resulted either from buckling of external columns by blast, or by a mass distortion of the structure away from the direction of blast, which disrupted the joints between columns and beams. Because Japanese residential areas were densely built up, walls were usually shielded from blast by adjacent buildings. Consequently, failure by mass distortion was probably the most characteristic damage effect since this could readily result from blast impinging on the roofs of buildings.

9. Fire Vulnerability

a. General opinion in the United States had been that Japanese dwellings were "tinder boxes." Considering the dwellings collectively in their natural surroundings in a congested city, this opinion is well founded; but considering an individual dwelling set off by itself, the evaluation is inaccurate.

b. Collectively, Japanese dwellings were extremely vulnerable to fire because of the high degree of built-upness of residential areas, light exterior wood sheathing, broad, open, wood eaves and air space under the first floor. All these features tend to assist fire spread. On the other hand, the heavy tile covering on the roofs practically precluded ignition of roofs by flying embers. Thatched roofs were found only outside city limits or in sparsely built-up areas.

c. Actually, frequency of fires in individual Japanese dwellings was less than one-half that in American homes. This situation can be attributed to the fact that the Japanese dwelling was generally less susceptible to ignition because of the lesser amount of combustible furnishings and higher moisture content of the wood and furnishings. In addition, there were fewer internal sources of ignition and more careful supervision by the occupants. Once a fire progressed beyond the stage of incipiency, however, the Japanese dwelling burned rapidly.

UNITED STATES STRATEGIC BOMBING SURVEY

LIST OF REPORTS

The following is a bibliography of reports resulting from the Survey's studies of the European and Pacific wars. Those reports marked with an asterisk (*) may be purchased from the Superintendent of Documents at the Government Printing Office, Washington 25, D. C.

European War

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*1 The United States Strategic Bombing Survey: Summary Report (European War)
*2 The United States Strategic Bombing Survey: Over-all Report (European War)
*3 The Effects of Strategic Bombing on the German War Economy

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(By Division and Branch)

*4 Aircraft Division Industry Report
5 Inspection Visits to Various Targets (Special Report)

Airframes Branch

6 Junkers Aircraft and Aero Engine Works, Dessau, Germany
7 Erla Maschinenwerke G m b H, Heiterblick, Germany
8 A T G Maschinenbau, G m b H, Leipzig (Mockau), Germany
9 Gothaer Waggonfabrik, A G, Gotha, Germany
10 Focke Wulf Aircraft Plant, Bremen, Germany
11 Messerschmitt A G, Augsburg, Germany { Over-all Report; Part A; Part B; Appendices I, II, III }
12 Dornier Works, Friedrichshafen & Munich, Germany
13 Gerhard Fieseler Werke G m b H, Kassel, Germany
14 Wiener Neustaedter Flugzeugwerke, Wiener Neustadt, Austria

Aero Engines Branch

15 Bussing NAG Flugmotorenwerke G m b H, Brunswick, Germany
16 Mittel-Deutsche Motorenwerke G m b H, Taucha, Germany
17 Bavarian Motor Works Inc, Eisenach & Durrerhof, Germany
18 Bayerische Motorenwerke A G (BMW) Munich, Germany
19 Henschel Flugmotorenwerke, Kassel, Germany

Light Metal Branch

20 Light Metals Industry of Germany { Part I, Aluminum; Part II, Magnesium }
21 Vereinigte Deutsche Metallwerke, Hildesheim, Germany
22 Metallgussgesellschaft G m b H, Leipzig, Germany
23 Aluminiumwerk G m b H, Plant No. 2, Bitterfeld, Germany
24 Gebrueder Giulini G m b H, Ludwigshafen, Germany
25 Luftschiffbau, Zeppelin G m b H, Friedrichshafen on Bodensee, Germany
26 Wieland Werke A G, Ulm, Germany
27 Rudolph Rautenbach Leichmetallgiessereien, Solingen, Germany
28 Lippewerke Vereinigte Aluminiumwerke A G, Lunen, Germany
29 Vereinigte Deutsche Metallwerke, Heddernheim, Germany
30 Duerener Metallwerke A G, Duren Wittenau-Berlin & Waren, Germany

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*31 Area Studies Division Report
32 A Detailed Study of the Effects of Area Bombing on Hamburg
33 A Detailed Study of the Effects of Area Bombing on Wuppertal
34 A Detailed Study of the Effects of Area Bombing on Dusseldorf
35 A Detailed Study of the Effects of Area Bombing on Solingen
36 A Detailed Study of the Effects of Area Bombing on Remscheid
37 A Detailed Study of the Effects of Area Bombing on Darmstadt
38 A Detailed Study of the Effects of Area Bombing on Lubeck
39 A Brief Study of the Effects of Area Bombing on Berlin, Augsburg, Bochum, Leipzig, Hagen, Dortmund, Oberhausen, Schweinfurt, and Bremen

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*40 Civilian Defense Division—Final Report
41 Cologne Field Report
42 Bonn Field Report
43 Hanover Field Report
44 Hamburg Field Report—Vol I, Text; Vol II, Exhibits
45 Bad Oldesloe Field Report
46 Augsburg Field Report
47 Reception Areas in Bavaria, Germany

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*48 German Electrical Equipment Industry Report
49 Brown Boveri et Cie, Mannheim Kafertal, Germany

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*50 Optical and Precision Instrument Industry Report

Abrasives Branch

*51 The German Abrasive Industry
52 Mayer and Schmidt, Offenbach on Main, Germany

Anti-Friction Branch

*53 The German Anti-Friction Bearings Industry

Machine Tools Branch

*54 Machine Tools & Machinery as Capital Equipment
*55 Machine Tool Industry in Germany
56 Herman Kolb Co., Cologne, Germany
57 Collet and Engelhard, Offenbach, Germany
58 Naxos Union, Frankfort on Main, Germany

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64 Description of RAF Bombing
64a The Impact of the Allied Air Effort on German Logistics

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*64b The Effects of Strategic Bombing on German Morale (Vol. I and Vol. II)

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*65 The Effect of Bombing on Health and Medical Care in Germany

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67 Coking Plant Report No. 1, Sections A, B, C, & D
68 Gutehoffnungshuette, Oberhausen, Germany
69 Friedrich-Alfred Huette, Rheinhausen, Germany
70 Neunkirchen Eisenwerke A G, Neunkirchen, Germany
71 Reichswerke Hermann Goering A G, Hallendorf Germany
72 August Thyssen Huette A G, Hamborn, Germany
73 Friedrich Krupp A G, Borbeck Plant, Essen, Germany
74 Dortmund Hoerder Huettenverein, A G, Dortmund, Germany
75 Hoesch A G, Dortmund, Germany
76 Bochumer Verein fuer Gusstahlfabrikation A G, Bochum, Germany

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*77 German Motor Vehicles Industry Report
*78 Tank Industry Report
79 Daimler Benz A G, Unterturkheim, Germany
80 Renault Motor Vehicles Plant, Billancourt, Paris
81 Adam Opel, Russelsheim, Germany
82 Daimler Benz-Gaggenau Works, Gaggenau, Germany
83 Maschinenfabrik Augsburg-Nurnberg, Nurnberg, Germany
84 Auto Union A G, Chemnitz and Zwickau, Germany
85 Henschel & Sohn, Kassel, Germany
86 Maybach Motor Works, Friedrichshafen, Germany
87 Voigtlander, Maschinenfabrik A G, Plauen, Germany
88 Volkswagenwerke, Fallersleben, Germany
89 Bussing NAG, Brunswick, Germany
90 Muehlenbau Industrie A G (Miag) Brunswick, Germany
91 Friedrich Krupp Grusonwerke, Magdeburg, Germany

Submarine Branch

92 German Submarine Industry Report
93 Maschinenfabrik Augsburg-Nurnberg A G, Augsburg, Germany
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95 Deutschewerke A G, Kiel, Germany
96 Deutsche Schiff und Maschinenbau, Bremen, Germany
97 Friedrich Krupp Germaniawerft, Kiel, Germany
98 Howaldtswerke A G, Hamburg, Germany
99 Submarine Assembly Shelter, Farge, Germany
100 Bremer Vulkan, Vegesack, Germany

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102 Friedrich Krupp Grusonwerke A G, Magdeburg, Germany
103 Bochumer Verein fuer Gusstahlfabrikation A G, Bochum, Germany
104 Henschel & Sohn, Kassel, Germany
105 Rheinmetall-Borsig, Dusseldorf, Germany
106 Hermann Goering Werke, Braunschweig, Hallendorf, Germany
107 Hannoverische Maschinenbau, Hanover, Germany
108 Gusstahlfabrik Friedrich Krupp, Essen, Germany

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*110 Oil Division, Final Report, Appendix
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113 The German Oil Industry, Ministerial Report Team 78
114 Ministerial Report on Chemicals

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116 Braunkohle Benzin A G, Zeitz and Bohlen, Germany
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117 Ludwigshafen-Oppau Works of I G Farbenindustrie A G, Ludwigshafen, Germany
118 Ruhroel Hydrogenation Plant, Bottrop-Boy, Germany, Vol. I, Vol. II
119 Rhenania Ossag Mineraloelwerke A G, Harburg Refinery, Hamburg, Germany
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121 Rhenania Ossag Mineraloelwerke A G, Wilhelmsburg Refinery, Hamburg, Germany
122 Gewerkschaft Victor, Castrop-Rauxel, Germany, Vol. I & Vol. II
123 Europaeische Tanklager und Transport A G, Hamburg, Germany
124 Ebano Asphalt Werke A G, Harburg Refinery, Hamburg, Germany
125 Meerbeck Rheinpreussen Synthetic Oil Plant—Vol. I & Vol. II

Rubber Branch

126 Deutsche Dunlop Gummi Co., Hanau on Main, Germany
127 Continental Gummiwerke, Hanover, Germany
128 Huels Synthetic Rubber Plant
129 Ministerial Report on German Rubber Industry

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130 Elektrochemischewerke, Munich, Germany
131 Schoenebeck Explosive Plant, Lignose Sprengstoff Werke G m b H, Bad Salzemen, Germany
132 Plants of Dynamit A G, Vormal, Alfred Nobel & Co, Troisdorf, Clausthal, Drummel and Duneberg, Germany
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140 Submarine Pens, Brest, France
141 Powder Plant, Angouleme, France
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144 Fort St. Blaise Verdun Group, Metz, France
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147 Gnome et Rhone Aero Engine Factory, Le Mans, France
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208 21 Rheinische-Westfalische Elektrizitaetswerk A G

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8 Field Report Covering Air Raid Protection and Allied Subjects, Osaka, Japan
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*18 Kawanishi Aircraft Company
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